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Research

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The Gluteus Medius Activation in Female Indoor Track Runners is Asymmetrical and may be Related to Injury Risk

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ABSTRACT

Track runners train and compete solely in the counter clockwise direction around the track. These repetitive motions place track runners at risk of "over-use" injury, but strength differences place females at greater risk than males. This study was conducted to evaluate the asymmetry of gluteus medius muscle activation patterns in female runners as they run around the curves of an unbanked 200 m track. Wireless surface electromyography (EMG) sensors were adhered to the skin overlaying the gluteus medius. Participants' muscle activation was recorded as they ran two 200 m trials at a pace of 5±0.5 m/s and walked 200 m at a chosen pace. Each participant's EMG for the running strides was normalized to the average amplitude of their walking trials. There were significant increases in muscle activation of the outside (right) gluteus medius when athletes ran on the curves compared to the straightaways (359.1 percent of walking ±132.8 and 324.7±102.6 respectively, p=0.015). There was a trend for decreases in muscle activation of the inside (left) gluteus medius when athletes ran on the curves compared to the straightaways (449.2 percent of walking ±136.1 and 469.4±132.6 and respectively, p=0.065). These data suggest that the gluteus medius abducted the outside (right) leg to contribute to the lateral forces necessary to run around the curve. The muscular demands for the two legs are different, and are consistent with observed injury patterns. This loading pattern and mechanism of injury may be useful for guiding training and rehabilitation strategies.

KEY WORDS: Running; Gait; Muscle activation; Gluteus medius; Straightaways; Curves; Asymmetry; Indoor track.

ABBREVIATIONS: EMG: Electromyography; ITBS: Iliotibial Band Syndrome.

INTRODUCTION

Running is a common recreational and competitive activity consisting of alternating stance and swing phases, and including an airborne phase.[1,2] The intermittent application of force on contact with the ground produces a peak vertical impact force equal to about 2.5 times a person's body weight,[3] Achilles tendon forces between 6.1 and 8.2 times body weight, and patellar tendon forces between 4.7 and 6.9 times body weight.[4] As a result, runners are prone to "over-use" injuries such as Achilles tendinopathy, chronic knee lesions (patellar cartilage lesions), iliotibial band syndrome and stress fractures.[5] International athletic competitions have relatively high rate of injury (81.1±4.2 injuries per 1000 athlete registrations),[6] and mixed findings about the injury rates in males and females. For example, a recent review of injuries in major track and field competitions concluded that males have a higher risk of injury than

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females,[5] a retrospective review of injuries sustained by 95 track and field athletes in a 12 month period observed similar injury rates in male and female athletes,[7] a recent systematic review that included a total of 4,671 pooled participants observed that most studies did not find that gender was associated with running injuries,[8] and a systematic review of injuries in recreational and competitive runners revealed a positive association between overall lower extremity running injuries and the female sex.[9] In addition, weak hip abductors and external rotators are associated with the development of general overuse injuries of the foot and ankle, patellofemoral pain, iliotibial band syndrome and anterior cruciate ligament injury.[10] Interestingly, decreased hip abductor concentric strength predicts the development of exertional medial tibial pain in females, but not males.[11]

Competitive track runners exclusively run around the curves of the track in the counter-clockwise direction. Compared to running in a straight path with prominent vertical ground reaction forces, running around curves requires larger lateral ground reaction forces[12] and different muscle activations.[13] While both legs of a runner generate lateral ground reaction forces when running around a curve, the resultant ground reaction force is significantly greater for the outside leg.[12] This asymmetry is also reflected in increased hind foot evertor strength of the right leg and hind foot inverter strength of the left leg of collegiate sprinters and middle distance runners after ten weeks of track training.[14] Right foot evertors and left foot invertors, in conjunction with hip abductors and hip adductors, are thought to produce the forces necessary for accelerating around the curves of the track.[14] While many studies have evaluated the kinematics[15,16] and ground reaction forces during running around curves,[12,17] fewer studies have evaluated the muscular patterns during running around curves and related cutting maneuvers.[13] These data have been interpreted in light of the maximum forces that limbs can generate and have led to the conclusion that the inside leg is the limiting factor during running around curves.[12] For example, the inside leg has smaller propulsive and lateral forces compared to the outside leg.[12] However, these papers specifically evaluate the force components along the leg and assume that the lateral component of the ground reaction force is produced by leaning into the corner such that the limb extensor force includes a lateral component.[17] If this were the case, then we would expect that the gluteus medius muscle activation would be similar in the straightaways and while running around curves. However, the hip abductor muscles on the outside leg can effectively produce an abduction moment during stance that would result in lateral ground reaction forces. If the hip abductors are contributing to the lateral ground reaction force then we would expect that there would be greater gluteus medius activation on the outside leg while running around curves compared to the straightaways. Given that running around curves requires laterally-directed components of the ground reaction force[12] and may place higher demands on the hip abductors,[14] and that females have weaker abductors than males,[18] females may show differential muscle activations and may be at a higher risk of injury while running on curved tracks.

The purpose of this study was to investigate the asymmetry of gluteus medius muscle activation patterns in female runners as they run around the curves of an unbanked 200 m track. Given the difference in function of the inside and outside legs while running around curves, we hypothesized specific directional hypotheses. We hypothesized that the right (outside leg) gluteus medius activation on curves would be significantly greater than straightaways, which is consistent with these muscles creating abduction moments to contribute to the lateral forces during curves. We hypothesized that the left (inside leg) gluteus medius activation on curves would be significantly less than straightaways, since abduction moments for the inside limb take away from centripetal forces during curves.

METHOD

Participants

Eight middle- to long-distance female runners of Western University's 2013-2014 Track and Field and Cross Country teams were recruited to participate. Volunteers signed a written consent letter and completed a Training and Medical History Form assessing their eligibility. All participants were between 18 and 27 years of age and currently not suffering from an injury resulting in abnormal running form. The participants' mean (± SD) age was 20±1.67 years, mean height (± SD) was 167.63±12.04 cm, mean (± SD) leg length was 102.75±6.39 cm and mean weight (± SD) was 57.50±6.46 kg. Each participant ran an average (± SD) of 7.44±1.24 hours per week and had been running for an average (± SD) of 8.50±2.83 years. During the indoor track season, an average (± SD) of 3.31±1.00 hours per week of training time consisted of running timed intervals in the counter-clockwise direction around the 200 m indoor track at Thomson Arena at Western University. The 10 mm polyurethane rubber track was unbanked and included 45 m straightaways and 55 m curves.[14] This study was approved by the UWO Ethics Review Board and Women's Track and Field Head Coaches, and all participants provided informed consent.

Participant Preparation

Wireless surface electromyography electrodes (Trigno™ Wireless Systems, DELSYS, Boston, MA, USA) with 10 mm inter-electrode distance were adhered midway between the crista iliaca and the greater trochanter to capture gluteus medius muscle activation.[19] Both lower extremities were instrumented. The skin was wiped with alcohol swabs to reduce impedance and to improve electrode adherence. The electrodes were arranged parallel to the muscle fibers and were secured to the skin using the manufacturer's double-sided tape interfaces, and additional strips of tape, to prevent electrode movement.

Maximal Voluntary Contractions and Strength Tests

Maximal hip abductor strength was tested three times per leg for each participant. Guidelines for manual resistance

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testing of the gluteus medius[19-21] were followed while providing resistance with a Mark-10 Series 5 digital force gauge (Mark-10 Corporation, Copiague, NY, USA), similarly to other researchers.[22] The examiner's standard command was "go-go-go-push-push" as the participant attempted to abduct her leg against manual resistance while laterally recumbent.[22] The participant held the contraction for four seconds and had two minutes of rest between contractions. Maximal strength was defined as the peak force recorded by the digital force gauge.

The digital force gauge was also used to measure hip flexor and adductor strengths. For hip flexor strength, the participant was in a seated position and maintained their thigh 8 inches from the surface of the chair.[22,23] With the digital force gauge in hand, force was manually applied onto the thigh to break the muscle contraction.[23] The peak force was recorded. For hip adductor strength, the participant was laterally recumbent with her knees extended.[24] The participant attempted to adduct her bottom leg without internal/external rotation, flexion or extension of the hip and a breaking force was manually applied below the knee.[24]

Testing Protocol

To warm-up prior to testing, the participants jogged at a warm-up pace for five minutes. Testing for each participant consisted of three 250 m trials around the innermost lane of the track, from the start of a straightaway around the track and to the end of that straightaway. Participants ran at a target pace of 5 m/s, the approximate race pace for a 3000 m race for the first two trials and walked at a self-selected pace for the third trial. Fifty meters into each trial the electromyography (EMG) system and manual stopwatch were started. At the completion of one lap of the track, the EMG system and stopwatch were stopped. Running trials exceeding ±0.5 m/s of the target speed were repeated. In between tests, participants rested for five minutes. Participants were videotaped from a viewing platform above the track using a Sony HDR-XR550V digital camera mounted on a tripod. The camera was panned to follow the participants as they walked and ran to determine when they were running on curves versus straightaways and times of foot contact.

DATA ANALYSIS

A two-way repeated measures ANOVA was used to compare peak strength measurements for participants hip abductors, hip adductors, hip extensors and hip flexors for their bodies' right and left sides.

The raw EMG signals were sampled at 2000 Hz, full-wave rectified and low-pass filtered with a 2nd order Butterworth (Fc=20 Hz). The videos were played frame-by-frame using VLC media player (version 2.1.4, Free Software Foundation, Boston, MA, USA) to record foot contact timing. The videotape recording was also used to code the strides as whether they occurred in the straightaway or curve. Individual strides for both the right and left sides were partitioned out of the data record using the timing of foot contacts extracted from the videotape recording. EMG data were normalized to walking on the straightaways to yield percent of walking values similarly to other researchers,[25,26] and the mean amplitudes were extracted to represent the magnitude of muscle activation. One-tailed paired t-tests were used to evaluate the statistical significance of differences in average gluteus medius EMG amplitudes between the straightaways and curves for right (outside) and left (inside) legs using Graph Pad Prism (version 6, Graph Pad Software, San Diego, CA, USA). Statistical significance was set at $p<0.05$.

RESULTS

Peak Strength

There was no significant interaction between sides and muscle group's strength ($p=0.924$), and no significant main effect of side ($p=0.928$). There was a statistically significant main effect of muscle group (Figure 1; $p<0.0001$). Post hoc testing revealed that the abductors were significantly stronger than the adductors ($p=0.049$), and the extensors were significantly stronger than the flexors ($p=0.007$) while no other comparisons were significantly different.

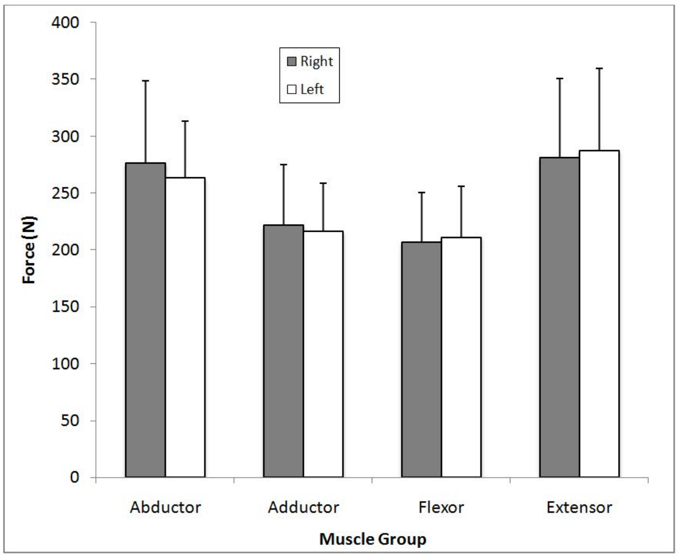

Figure 1: Maximal hip strengths for the right and left sides. The differences between the right and left sides were not statistically significant.

Muscle Activation

We observed that the gluteus medius showed a burst of activity during stance (Figure 2). In general the gluteus medius was activated between three and five times greater during running than walking (Figure 3). Interestingly we observed that the right gluteus medius muscle appeared to be activated less than the left for both straightaways and curves. When we compared between curves and straightaways for each side, we observed significantly greater activation for the right (outside leg) gluteus

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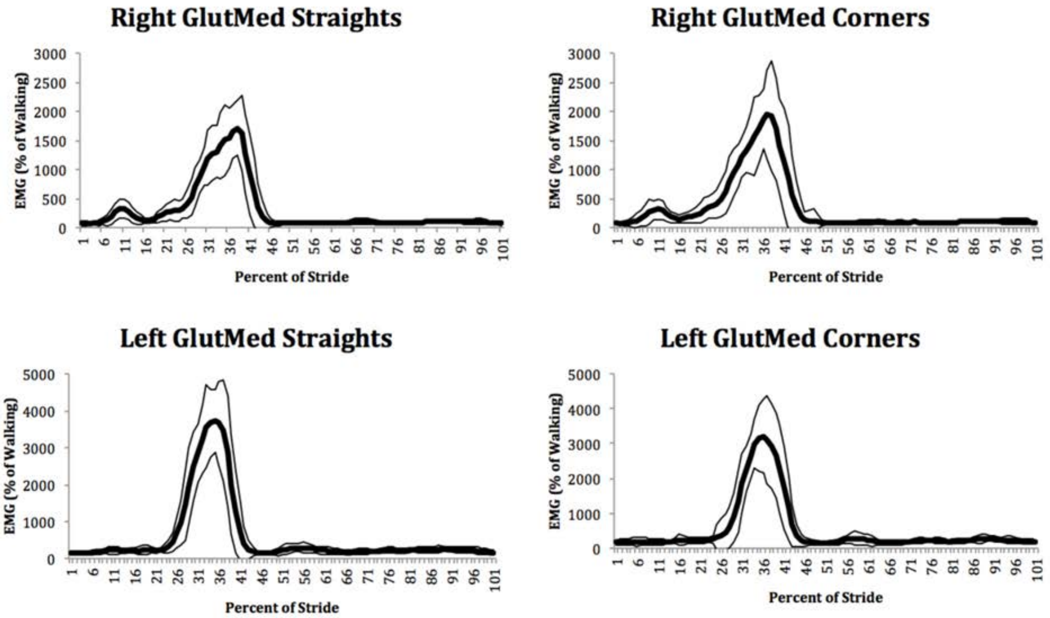

Figure 2: Ensemble average patterns of gluteus medius muscle activation for the right and left sides, and for straightaways and curves for a representative participant. The mean values are shown with the thick line and the narrow lines represent plus and minus one standard deviation from the mean. The running stride extends from foot contact (0 percent of stride) to subsequent foot contact (100 percent of stride).

medius in curves compared to straightaways (p=0.015), and a trend towards less activation of the left (inside leg) gluteus medius on the curves compared to the straightaways (p=0.065).

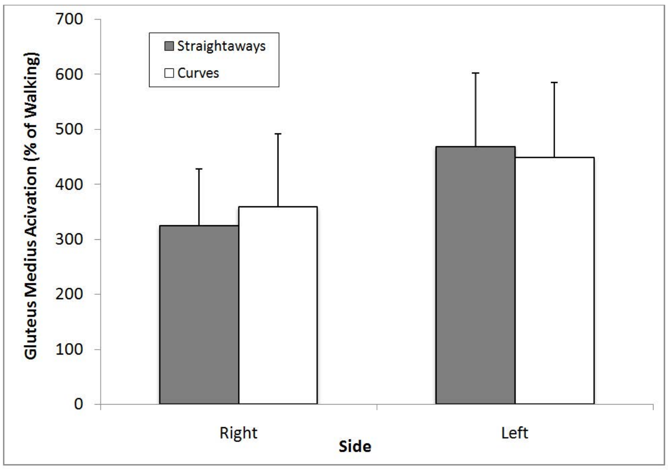

Figure 3: Mean muscle activation (±SD) of the left (inside) and right (outside) gluteus medius for runners on curves versus straightaways. There was a significant increase in gluteus medius activation on the right side in curves compared to straightaways. There was a trend towards decreases in gluteus medius activation on the left side in curves compared to straightaways.

DISCUSSION

The purpose of this study was to determine if the gluteus medius contracts asymmetrically when female runners run around the curves of a 200 m unbanked track. Given the necessity for increased lateral ground reaction forces,[12,27] we hypothesized that the magnitude of gluteus medius activation of female runners would be different between straightaways and curves for the right (outside) and left (inside) legs. In specific, we hypothesized increased activation of the right (outside) gluteus medius in curves, and decreased activation of the left (inside) gluteus medius in curves. The results of the study supported our hypotheses: gluteus medius activation in curves was significantly greater for the right (outside) leg, and we observed a trend for decreased gluteus medius activation of the left (inside) leg in curves compared to straightaways when female runners ran on an unbanked 200 m track. These data suggest that the biomechanical and muscular demands of curvilinear running differed from those of straight path running. Previous studies have thought that extension of the leg with the body leaning into the corner produces the required lateral forces,[28,29] and that the inside leg limits curve sprinting performance.[12] Although these ideas may have some merit, we have determined that the hip abductor muscles, particularly on the right (outside) leg, play a significant role in generating the lateral forces necessary for turning. These demands may place female track runners at increased risk for injury.

Our findings are consistent with studies that have determined that the outside leg generated greater peak lateral GRFs[12,30] and larger lateral impulses[27,30] compared to the inside leg. Our findings are also consistent with a study that observed that the trunk lean angle increases while the outside foot is on the ground and decreases when the inside foot is on the ground.[31] Similarly, our findings are consistent with a study that observed increases in right side gluteus medius activation during left turns in open cutting maneuvers, though this difference was not statistically significant.[13] They observed that the bursts of raw EMG occurred in swing, which they interpret as performing medial rotation of the femur in preparation for foot contact. However, the delay between the EMG signal and the production of force[32] means that this activation would actually result in forces during stance. Other researchers have also noted that the gluteus medius is active during stance.[33] Accordingly the gluteus medius activation was abducting the hip while the foot is planted, leading

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to laterally directed ground reaction forces. These lateral forces during stance, primarily from the outside limb,[30] provide the centripetal force necessary to change the direction of the runner, allowing them to run around the curve.[12] Some authors have presented contrasting understandings of the roles of the inner and outer legs in running. For example, Alt et al.[15] concluded that the inside leg provided stability in the frontal plane (eversion-adduction strategy) while the outside leg provided motion in the horizontal plane (rotation strategy), although their rationale was based upon stance durations and joint kinematics rather than kinetics or EMG.

Previous studies have determined the gluteus medius stabilizes the hip before and after stance phase during straight path running.[34] The present study extends these findings by documenting gluteus medius' secondary role in hip abduction.[35]

The uniformity in hip abductor, hip adductor, hip extensor and hip flexor strengths for participants left and right sides indicated that participants did not have pre-existing strength asymmetries. It is important to note that we attempted to carefully control body position, as research has shown that variations, such as side-lying hip abduction and internal rotation angles, influence amount of muscle activation,[36] and presumably force. Although all of the participants in this study were highly trained track runners (members of the Varsity Track and Field team), it is possible that increased muscle activation of the outside (right) gluteus medius in curvilinear running may lead to muscular asymmetry, as observed in hindfoot invertor and evertor muscles.[14] It is important to note that the role of hindfoot muscle groups is similar to the hip abductors/adductors during curvilinear running;[14] both are responsible for producing forces that allow a runner to accelerate around a curve.

The greater demands on the right (outside) leg gluteus medius during curves may place female track runners at increased risk for injury. Repeated asymmetrical muscle activation with existing muscle weakness may result in "over-use" injuries of the lower extremities.[37] In fact, there appears to be a relationship between hip abductor strength and iliotibial band syndrome (ITBS); long distance runners with ITBS have weaker hip abduction strength in the affected leg compared to their unaffected leg, and also compared to unaffected long-distance runners.[38] They also observed that symptom relief with a successful return to the preinjury training program paralleled improvement in hip abductor strength.[38] Thus, to reduce the risk of injury, coaches may wish to supplement track running with strength training targeting hip abductors.[38,39] Other studies have shown asymmetries in strength,[38] and that large increases in hip muscle strength can be achieved in a two month duration unsupervised exercise program.[40] This issue may be more relevant for female track runners as they are at greater risk than male track runners of developing iliotibial band syndrome and other hip-related injuries.[41,42]

Although it was not related to our hypotheses, and therefore was not evaluated statistically, the gluteus medius muscles on the right side appeared to be activated less than the left side. While many studies only measure EMG from muscles on one side of the body and assume bilateral symmetry (for example[43,44]), previous studies of walking found bilateral asymmetries in participants for six of seven leg muscles.[45] Asymmetry has also been emphasized in gait[46] and running.[47] Given that we normalized our running EMG trials to the walking trials, the asymmetry that we observed might have been caused by either the walking and/or the running trials, but was not caused by bilateral differences in maximum strength.

LIMITATIONS

The present study analyzed muscle activity when runners ran at one speed around an unbanked track. Other researchers have identified that running speed influences the ground reaction forces[30] and the muscle activation levels,[44,48] so our findings only reflect running at a steady 3000 m race pace (5 m/s). Accordingly our findings may not be applicable to running at other speeds, at other track radii, while accelerating, or on banked tracks. Our EMG measurements were limited to the gluteus medius muscle, and accordingly we do not have insight into the roles of other abductors[49,50] or other lower extremity muscles. Fine-wire EMG may be useful for evaluating the functionally distinct regions of the gluteus medius.[33] Our participants were all highly trained members of the female Varsity Track and Field team, and accordingly our findings may not be applicable to other groups. Further research should expand the one-dimensional models of running on a curved path, such as the maximum leg extension force model, to consider the contribution of the hip abductors.

CONCLUSION

In summary, the present study has demonstrated that the gluteus medius contracts asymmetrically in female runners as they run around the curves of an unbanked, 200 m indoor track. This activation in participants' outside (right) leg likely contributes to lateral forces and centripetal accelerations necessary to run around the curves. This hip abductor mechanism may be a performance constraint for curved running. Furthermore, this asymmetrical muscle activation may lead to injury in track runners, with females at even greater risk than males. Coaches may want to consider injury prevention strategies such as training around both directions of the track, and complementing running with strength training to prevent the development of muscle strength asymmetry, or to correct it if it is present.

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CONFLICTS OF INTEREST: None.

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