Association Between Hip Rotation and Activation of the Quadriceps and Gluteus Maximus in Male Runners

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Background: Although running can provide health benefits, knee joint injuries are frequently reported by recreational runners. To date, the precise mechanism responsible for anterior knee pain remains elusive, and the source of symptoms is debated. Inconsistencies are found in the literature pertaining to the relationship between hip mechanics and activity in the quadriceps and gluteus maximus (GMax) during the running gait.

Purpose/Hypothesis: To investigate the correlations between hip rotation and the activity in the quadriceps and GMax during running. We hypothesized that increased hip rotation is correlated with decreased activity in these muscles.

Study Design: Descriptive laboratory study.

Methods: A cohort of 30 healthy recreational runners volunteered to participate in the study (mean ± SD age, 28.8 ± 5.66 years; height, 1.73 ± 0.05 m; mass, 69 ± 6.3 kg; body mass index, 23.02 ± 1.42 kg/m^2). Surface electromyography (EMG) data were obtained from the GMax, vastus medialis obliquus (VMO), and vastus lateralis obliquus (VLO). These data were synchronized with a motion capture system during a level-surface running activity at a speed of 3.2 m/s.

Results: A significantly strong, negative correlation was found between the hip internal rotation angle and EMG activity of the GMax and the VMO. However, the VLO showed a significant, moderate, and positive correlation of activity with the hip internal rotation angle.

Conclusion: The present study showed that during level-surface running, decreased GMax activity may be the cause of distal joint injuries and alteration in quadriceps muscle activity.

Clinical Relevance: Because GMax activity is important for controlling the lower body mechanics during running, evaluating GMax activity and internal hip rotation angle is important to prevent the running-related knee injuries that are linked to quadriceps deficits, such as patellofemoral pain. Additionally, clinicians and trainers should consider strengthening the GMax while rehabilitating running-related knee injuries.

Keywords: hip internal rotation; gluteus maximus; quadriceps; EMG

Running is the sport of choice for many individuals, owing to its simplicity, health benefits, and low cost.[46,48] Although running can provide health benefits, musculoskeletal injuries are frequently reported by recreational runners, especially in the lower extremities. The prevalence of these injuries ranges from 7.5% to 90%, and particularly high rates of injuries have been documented in the knee joint.[8,17, 22] Among all types of knee injury, patellofemoral pain (PFP) accounts for the most common running-related injuries (RRIs), with incidence rates in the range of 3% to 40% in active populations.[5,31, 33] Upon completion of rehabilitation, approximately 80% of individuals who had PFP experienced the same pain at their 5-year follow-up, and almost 74% were instructed to decrease their performance level.[3] This may be attributed to a failure to address the fundamental factors that led to increased incidence of PFP.[47]

To date, the precise mechanism of anterior knee pain is unclear, and the sources of the symptoms in PFP are highly debated. A range of genetic, environmental, and training factors are possible contributors to PFP and joint stress distribution.[12,33] These stresses result from patellar maltracking and/or patellar compression against the trochlea of the femur.[11] A number of studies have suggested specific mechanisms and have correlated these with decreased hip strength. Specifically, the abductors and external rotators have been identified as muscles that could lead to stresses such as hip internal rotation.[30,49] This relates to findings by Souza and Powers,[42] who concluded that runners with PFP displayed a significantly higher dynamic hip internal rotation (8.2° vs 0.3°) during the stance phase of running. In

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addition, runners with PFP displayed a decreased hip extension torque that served as an indicator of the degree of internal rotation of the hip during running. Another proposed mechanism related to the incidence of PFP is increased quadriceps angle and quadriceps muscle strength deficit.[13,16,26,27,37]

Factors proximal and distal to the knee joint can alter knee mechanics and result in PFP.[11] However, it is unclear how the pathomechanics of the hip joint affect muscular control around the knee joint during the execution of functional tasks. Therefore, the current study aimed to explore the correlations between hip rotation in the stance phase and activation of the gluteus maximus (GMax), vastus medialis obliquus (VMO), and vastus lateralis obliquus (VLO) during running. Since the RRIs at the knee joints related quadriceps muscle strength deficit and higher dynamic hip internal rotation, we hypothesized that there would be significant decreases in quadriceps and GMax activity associated with increased hip rotation angle. The strength of the GMax may be the most important factor in the assessment, prevention, and rehabilitation of RRIs at the knee joint. Thus, this study was designed to test the main hypothesis that increased hip rotation is correlated with decreased quadriceps and GMax activity during running.

METHODS

Sample Characteristics

An a priori power analysis (G*Power software) indicated that a sample of 20 participants would be appropriate to establish a statistical power of 0.95, at the predetermined α level of .05, and with a large effect size of 0.7. A pilot study was undertaken to obtain an estimate of the proper sample size calculation. This pilot study involved 10 volunteers recruited to explore the correlation between hip rotation in the stance phase and electromyographic (EMG) activity of the GMax, VMO, and VLO muscles during running. Data from pilot testing were used to estimate the effect size with the use of the G*Power software. After institutional review board approval was obtained, 30 healthy male recreational runners participated in this study (mean ± SD age, 28.8 ± 5.66 years; height, 1.73 ± 0.05 m; mass, 69 ± 6.3 kg; body mass index, 23.02 ± 1.42 kg/m^2). To be included in the present study, a participant had to fulfill all of the following requirements: (1) between 18 and 40 years of age (this age range was carefully chosen to represent the young, athletic population for whom the results of the study are more likely to be relevant[23]); (2) healthy with no history of lower limb surgeries or injuries; (3) routinely running a minimum of 15 miles per week (a total of 3 training sessions per week) for a minimum of 3 months before recruitment to the study. Participants were excluded from the study if they did not fulfill all of the aforementioned criteria or if they participated in an injury-prevention program, as this may have altered the runner's natural kinematic and muscle activation patterns. All participants were instructed to wear the same model of running shoe (New Balance, M539SR) to eliminate any variability owing to shoe-surface interface as well as to negate any potential effects on lower limb biomechanics. In addition, use of the same training shoes controls the effects of different designs of shoes and the support they provide to individual performances.[14] Even a relatively small change in rearfoot motion as a result of different types of running shoes could be clinically significant given the vast number of foot strikes associated with running.[4,32]

Measuring Devices

3D Motion Capture. A motion-analysis system that consisted of 10 cameras (Pro-Reflex; Qualisys) with a sampling frequency of 250 Hz and 3 force platforms (AMTI) embedded in the running track, sampled at 1200 Hz, was used to gather biomechanical data for the lower limbs. The calibration anatomic systems technique, which consisted of anatomic landmark markers and tracking markers, was used to define movements with 6 degrees of freedom for each segment during the dynamic tasks.[7] All of the data-collection trials entailed 40 reflective markers that were 14.5 mm in diameter (20 markers on each lower limb) (Figure 1). Hypoallergenic double-adhesive tape was used to position the flat-base markers on the participant's skin as follows: iliac crest, anterior-superior iliac spine, posterior superior iliac spine, greater trochanter, medial and lateral femoral epicondyles, and medial and lateral malleoli. Foot markers were positioned on the first, second, and fifth metatarsal heads as well as the calcaneal tubercle over the standard shoes. The anatomic frames were rigid clusters that consisted of 4 nonorthogonal markers that were placed over the lateral shank and on the lateral thigh of the limbs.

Each participant was instructed to perform a standing trial and run on a 15-m walkway at a speed of 3.2 m/s (±5%). The running speed was controlled with optical timing gates

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Ethical approval for this study was obtained from the University of Salford (application HSCR16-44).

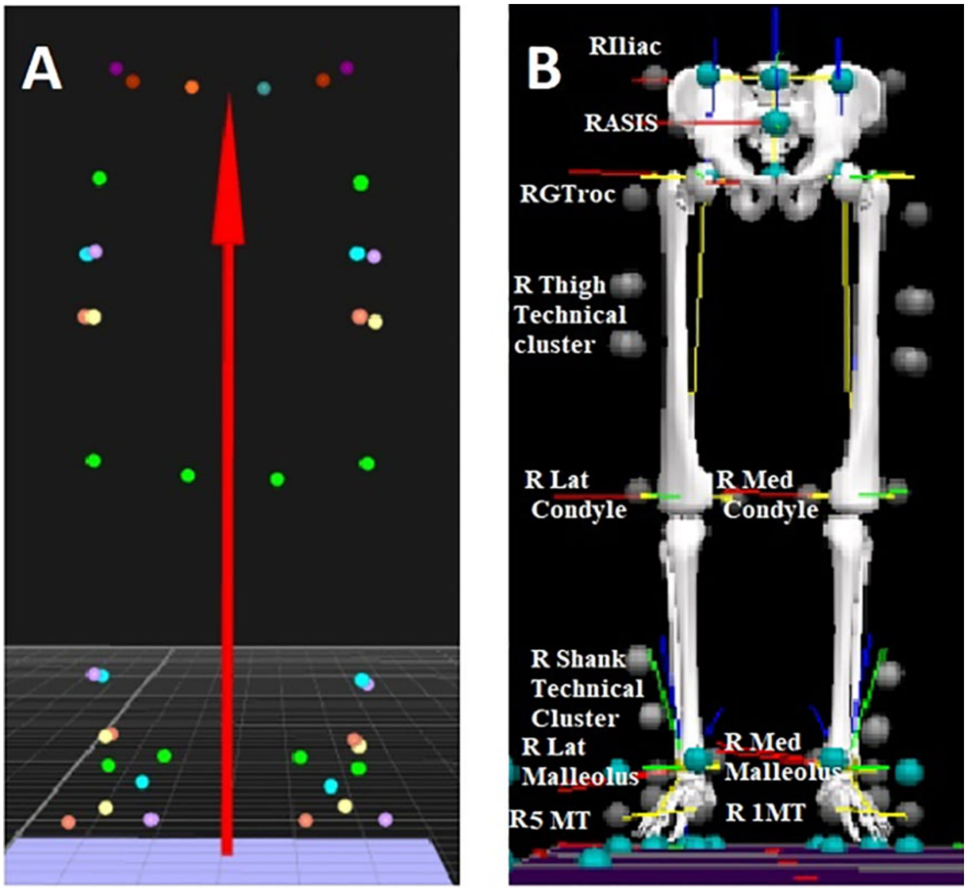

Figure 1. (A) Qualisys Track Manager static model. (B) Visual 3-Dimensional Tracker Manager standing bone model (red, *x*-axis; green, *y*-axis; blue, *z*-axis). R 1MT, right first metatarsal head; R 5MT, right fifth metatarsal head; R Lat Condyle, right lateral femoral condyle; R Lat Malleolus, right lateral malleolus; R Med Condyle, right medial femoral condyle; R Med Malleolus, right medial malleolus; RASIS, right anterior-superior iliac spine; RIliac, right iliac crest; RGTroc, right greater trochanter.

(Brower Timing Gate System; TC-Timing System). To minimize the possible effect of participant accelerations, the change in speed was carefully monitored based on the anteroposterior ground-reaction force. This was quantified based on an estimation of the difference in braking (–) and acceleration (+) portions of the anteroposterior ground-reaction force. When this difference was >10% of the total rectified anteroposterior ground-reaction force (ie, the mean absolute impulse), the trial was rejected. With this approach, trials in which there was evidence of any acceleration or deceleration were rejected. Trials were considered unsuccessful and eliminated from further analysis when they met 1 or more of the following standards: (1) there were <3 markers per segment visible, (2) they exceeded the acceptable range for speed and acceleration, or (3) there was a presence of partial or double contact with the force platforms.

Electromyographic Procedures. The measured muscles were located according to the surface EMG for noninvasive assessment of muscles (SENIAM) guidelines.[18,40] Thereafter, the skin over the predefined points was shaved with a disposable razor, and a special abrasive skin preparation (Nuprep Gel) was applied to the electrode site with a gauze pad to remove the dead skin. The skin area was then cleaned with 70% isopropyl alcohol and left for 2 minutes to dry. Finally, self-adhesive Ag/AgCl Noraxon bipolar, dual-surface electrodes (spacing of 20 mm) were placed over the prepared sites in line with the muscle fibers.

Surface EMG data were obtained from the GMax, VMO, and VLO, and the acquisition was synchronized with the motion capture system. The SENIAM guidelines for electrode placements were used to minimize the possibility of crosstalk between muscles.[19] For GMax, the participants lay face down, and the electrodes were placed at locations 50% along the line between the second sacral vertebrae and the greater trochanter. For VMO, the participants sat with their knees in slightly flexed positions, and the electrode was placed distally at a distance equal to 80% in front of the anterior border of the medial collateral ligament along the line between the anterior-superior iliac spine and the joint space. To ensure that the alignment was parallel to the muscle fibers, the electrode was placed at an angle of 55° with respect to the vertical line.[45] For VLO, the electrode was placed two-thirds on the line from the anterior-superior

TABLE 1
Pearson Correlation Coefficients (r) and Significance Levels (P) Between the Internal Rotation Angle of the Hip and EMG Activity for the GMax, VMO, and VLO[a]

	EMG Activity		
	GMax	VMO	VLO
Hip internal rotation			
r	−0.65[b]	−0.62[b]	0.52[b]
P	.001	.003	.007

[a] GMax, gluteus maximus; EMG, electromyographic; VLO, vastus lateralis obliquus; VMO, vastus medialis obliquus.

[b] Significant correlation.

iliac spine to the lateral side of the patella. Similar to VMO, the electrode was placed at an angle of 15° with respect to the vertical line to ensure that the alignment was parallel to the muscle fibers.[10] After the gait assessment (described above), a set of reference contractions were collected in order to normalize the gait EMG data. This included the recording of EMG signals from the tested muscles during a maximal voluntary isometric contraction.

After data collection, EMG data were exported to MATLAB (Version 18; MathWorks) for processing. This involved the use of an initial 30-Hz high-pass filter to remove noise and movement artifacts, followed by signal rectification and low-pass filtering (6 Hz Butterworth) to establish a linear envelope. The EMG amplitudes were then time-normalized to the stance period with the use of the gait event data captured from the force platforms. The same procedure was used to process the data regarding maximal voluntary isometric contraction, and a moving window algorithm was then used to determine the 0.1-second window within which the maximum EMG amplitude occurred. This maximum EMG value was then used to normalize the EMG data obtained in dynamic running trials.

Statistical Analysis

The normality assumptions of parametric statistical tests were evaluated based on Q-Q plots and the Shapiro-Wilks test. All data were determined to meet the assumptions for parametric testing. The Pearson correlation coefficient (r) was then calculated to determine the association between the independent variable (hip rotation angle) and the dependent variables (EMG activity of the GMax, VMO, and VLO). To determine the strength of the association, the following guide was used: $r = 0\text{-}0.19$ was regarded as a very weak correlation, $r = 0.2\text{-}0.39$ as weak, $r = 0.40\text{-}0.59$ as moderate, $r = 0.6\text{-}0.79$ as strong, and $r = 0.8\text{-}1$ as very strong.[6] The level of statistical significance was set at $P < .05$. The statistical analysis was carried out with the Statistical Package for the Social Sciences (SPSS) (Version 23; IBM).

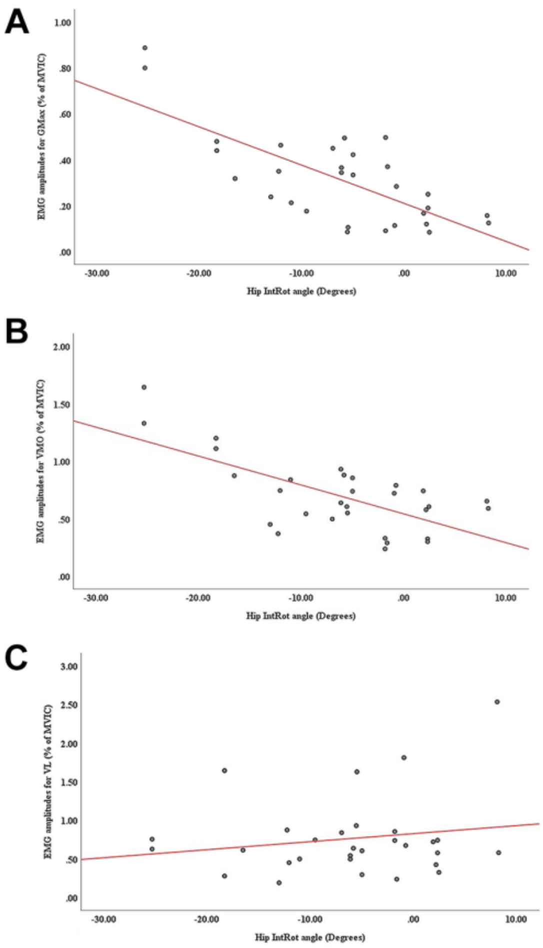

Figure 2. Associations between the rotation angle of the hip and electromyographic (EMG) activity for (A) gluteus maximus (GMax), (B) vastus medialis obliquus (VMO), and (C) vastus lateralis obliquus (VLO). IntRot, internal rotation; MVIC, maximal voluntary isometric contraction.

RESULTS

Table 1 displays the association between the hip rotation angle and the EMG activity for the GMax, VMO, and VLO muscles. A strong and significant negative correlation was found between the internal rotation angle of the hip and EMG activity for GMax and VMO (Figure 2, A and B). VLO exhibited a significant but moderate, positive correlation with the internal rotation angle of the hip (Figure 2C).

DISCUSSION

This study demonstrated 2 crucial, clinically relevant findings. One, significant negative correlations were observed between hip internal rotation angle and EMG activity for the GMax and VMO. Two, VLO exhibited a significant but positive correlation with the internal rotation angle of the hip. To the best of our knowledge, no current studies have reported the relationship between the rotation angle of the hip measured during the stance phase of running and the EMG activity of the GMax, VMO, and VLO muscles. Therefore, this is the first study to report on this potential link. We found that during running, the topmost internal rotation of the hip was developed at foot contact and followed by external rotation throughout the rest of the stance. The excessive internal rotation of the hip was combined with a greater knee valgus that could result in a greater dynamic quadriceps angle.[15] Additionally, the hip extensors functioned concentrically to extend the hip in the first half of the stance phase. Previous studies reported that movements were controlled by the GMax, which was the primary hip extensor and external rotator.[29] However, the quadriceps contracted eccentrically,[35] and greater EMG activity of the vastus medialis was seen with running.[15] This activity was significantly increased during internal knee rotation.[36]

Altered mechanics of any segment of the lower extremity can result in associated injuries to other segments of the lower extremity in running athletes.[11,42] Because of the close attachment of the lower extremity segments through the kinematic chain, each segment transfers forces and movements to the neighboring joints in a predictable pattern. Therefore, when abnormal mechanics occur at a specific joint, the dysfunction will transfer to the following joint in sequence.[28] In our study, the results showed a significant, negative correlation between the internal hip rotation angle and EMG activity of the GMax and VMO while running. These findings supported the hypothesis that increases in hip rotation angle were associated with changing activity in the tested muscles. These relationships may explain many RRIs that occur in the lower extremity joints, predominantly in the knee. Therefore, excessive internal rotation of the hip during running can potentially disturb the kinematics of the entire lower extremity. Excessive internal rotation of the hip may contribute to decreased GMax activity (hip external rotators) with lesser control on transverse plane movements.[29] Moreover, excessive internal rotation of the hip could move the knee joint center medially in relation to the foot. Owing to the contact of the foot with the ground during the stance phase of running, the tibia tends to abduct and the foot tends to pronate, thus resulting in a dynamic knee valgus.

The results of the current study are consistent with those of previous studies which found that the reduced strength of the external rotators of the hip was highly associated with the weightbearing knee valgus. However, no direct comparison can be made with the present study because of the different tasks performed (landing, single-limb squat, and step-down rather than running).[9,21,24,51] Additionally, previous work proposed that foot pronation was also associated with the internal rotation of the hip during walking.[43] Therefore, decreased activity of the GMax (as a proximal factor) produces an increase in the internal rotation of the hip, knee valgus, and foot pronation and leads to numerous distal injuries at the knee joint. The previously described combined mechanism (ie, hip internal rotation, knee valgus, and rearfoot eversion) has been found to be associated with injuries in runners.[28] Moreover, it has been reported that excessive knee valgus contributes to several knee injuries, such as anterior cruciate ligament (ACL) injuries[20] and PFP.[39] A combination of increased hip internal rotation and valgus knee landing could induce considerable strain on the ACL.[24] This is consistent with the findings of Souza and Powers,[42] who stated that female runners with PFP had diminished hip extension endurance that could influence the amount of internal rotation of the hip that occurred during running.

The findings of the current study showed a strong negative correlation between the internal rotation of the hip and the EMG activity of VMO. These findings may be attributed to the diminished activity of GMax, as mentioned earlier. The atypical GMax activation pattern associated with internal rotation in the hip joint that leads to excessive knee valgus can subsequently alter the quadriceps angle. This proposed mechanism will be followed by changes in the activation pattern of the quadriceps muscles, while it can concurrently control the knee joint (ie, it can cause decreases in VMO and increases in VLO activity). The degree of the quadriceps angle directly affects the force applied to the patella through the quadriceps. The greater the quadriceps angle, the higher force applied to the patella.[34] In turn, this influences the track of the patella in the trochlear groove.[39] The data presented in this study support the idea that decreased activation of the GMax occurs in conjunction with decreases in VMO and increases in VLO activation, thereby suggesting that altered knee extensor force produces larger, laterally directed forces on the patella.

No similar studies are available in the literature that would allow direct comparisons with the current results; however, previous investigators hypothesized that increased internal hip and knee abduction moments during running resulted in higher force magnitudes on the lateral facet of the patella. This greatly contributed to the force generated by the vastus lateralis, extensions of the iliotibial band, or both.[44,50] The abnormal tracking of the patella accounts for several knee injuries, especially during weightbearing activities. For instance, the quadriceps muscle is responsible for generating the knee extensor moment during the early phase of stance in running. This important role of the quadriceps prepares the limb for ground contact and helps attenuate the impact due to the ground-reaction force.[35] Subsequently, the greater demand on the quadriceps could result in higher compressive force through the patellofemoral joint. These excessive forces may aggravate PFP symptoms and inflammation. This explanation is supported by the findings of Lee et al,[25] who suggested that the abnormal increase in quadriceps angle constituted a risk factor for numerous knee overuse injuries. Those investigators additionally proposed that reduction of the quadriceps angle could be an effective measure to assess the efficacy of weightbearing therapeutic exercises on the muscle activation pattern in elite athletes with PFP.

It has been shown that the gluteus medius (GMed) is activated just before the initial contact and ends at approximately 55% of the stance phase. At the initial contact phase, the GMed may attempt to control the degree of hip adduction by acting as an antagonist to hip adductor forces. As the limb moves into the midsupport phase, the GMed continues eccentrically to maintain a level pelvis from which the swing leg moves. At takeoff, the GMed contracts concentrically to initiate hip abduction.[1] It was considered that inadequate GMed strength resulted in poor frontal plane pelvic control, whereas running may contribute to several RRIs.[41] The results of the current study are partly consistent with the findings of Bell et al[2] and Palmer et al,[38] who investigated the effect of an exercise training program of hip extension and abduction on knee kinematics. They found no significant correlation between hip abduction strength and the dynamic knee valgus and internal rotation; however, weakness of the hip extensors may result in excessive femoral adduction and internal rotation. This was proven by the significant correlation between the hip internal rotation angle and GMax, observed in the present study.

Limitations

The present study was subjected to some limitations that warrant consideration. The study population was restricted to young, fit, lean male runners who were physically active and ran at least 15 miles per week. It is possible that this study group could not capture the true variability across the demographic spectrum, and therefore, further research is necessary to study female runners, elite runners with weekly higher mileages, and more sedentary cohorts. Moreover, participants in the current study wore standardized training shoes on a standardized running surface. Therefore, it is unclear whether similar outcomes would be obtained when athletes run on different surfaces with different footwear. Future studies should be conducted in which participants wear their own training shoes and use a range of different running surfaces. Finally, the study was limited to 1 speed, because exploring the effect of running at different speeds on the muscle activation pattern was beyond the scope of this study. Therefore, further studies are needed to understand whether the link between the hip rotation angle and the activation pattern of VMO, VLO, and GMax is consistent across different speeds.

CONCLUSION

Abnormal proximal mechanics could alter the distal joint loading and subsequently lead to numerous RRIs during running. For instance, an atypical GMax activation pattern could allow for excessive internal rotation of the hip joint that could, in turn, result in excessive knee valgus and rearfoot eversion. The proposed mechanism could influence the quadriceps angle and consequently alter the activation patterns of VMO and VLO, which could cause a number of RRIs. These findings highlight the important functional role of hip extensors in controlling lower body mechanics while running. In addition, the results of the present study will contribute to future research into the efficacy of rehabilitation programs aimed at restoring normal hip mechanics during running instead of focusing on quadriceps strength.

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