Hip Abductor Weakness and Lower Extremity Kinematics During Running

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Objective: To determine if females with hip abductor weakness are more likely to demonstrate greater knee abduction during the stance phase of running than a strong hip abductor group. Study Design: Observational prospective study design. Setting: University biomechanics laboratory. Participants: 15 females with weak hip abductors and 15 females with strong hip abductors. Main Outcome Measures: Group differences in lower extremity kinematics were analyzed using repeated measures ANOVA with one between factor of group and one within factor of position with a significance value of $P < .05$. Results: The subjects with weak hip abductors demonstrated greater knee abduction during the stance phase of treadmill running than the strong group ($P < .05$). No other significant differences were found in the sagittal or frontal plane measurements of the hip, knee, or pelvis. Conclusions: Hip abductor weakness may influence knee abduction during the stance phase of running.

Epidemiological studies of recreational and competitive runners have estimated that between 27 and 70% of those who regularly participate in this sporting activity will sustain an overuse injury to the lower extremity in any one-year period. The etiology of these injuries has generally been linked to inappropriate training, lower extremity malalignments, and abnormal interactions between the shoe and the support surface. Although few studies have cited gender as a significant risk factor for running injuries, a report by Taunton et al. stated that women were twice as likely to sustain an overuse injury such as patellofemoral pain syndrome and iliotibial band syndrome compared with males. Several other studies have suggested that gender may play a role in the occurrence of overuse injuries in runners.

Biomechanical differences between male and female running kinematics have been reported in the literature. Malinzak et al. and Ferber et al. reported that females demonstrated significantly greater knee abduction during the stance phase of running compared with males. Ferber et al. also reported that female runners
demonstrated greater peak hip internal rotation and adduction during stance. Both of the authors suggested that these kinematic differences may be a potential source of injury to the ligamentous and musculoskeletal structures surrounding the knee.\textsuperscript{9,10} They also speculated that differences in the neuromuscular recruitment patterns between males and females may play a role in their kinematic findings.\textsuperscript{9,10}

Similar gender-related knee kinematic findings have been reported in the literature for various activities such as landing, cutting, and performing a single leg squat.\textsuperscript{11-14} These biomechanical differences are now considered a significant risk factor for ACL injury in the female athlete. Several authors have suggested that a lack of strength in the proximal hip stabilizers may contribute to these gender differences during athletic performance.\textsuperscript{14-17} In their kinematic and EMG study of males and females completing a single leg squat, Zeller et al\textsuperscript{17} reported that the mean maximum EMG activation for the gluteus medius was 77.3\% of maximum voluntary contraction for males and 41.0\% for females. Zeller et al\textsuperscript{17} also reported that the female subjects demonstrated greater knee abduction during this closed chain activity and suggested that this kinematic difference in performance of a single leg squat may be related to gender differences in muscle activation patterns of the hip.

In a study of core strength measurements as risk factors for lower extremity injury in male and female basketball players and cross country runners, Leetun et al\textsuperscript{18} reported that athletes who did not sustain an injury were stronger in the hip abductors and external rotators than the injured athletes were. A logistic regression analysis revealed that hip external rotator strength was a useful predictor of injury occurrence.\textsuperscript{18} These authors also reported that the female athletes were significantly weaker in the hip abductors, hip external rotators, and scored lower during endurance testing of the back extensors and lateral trunk.\textsuperscript{18} In a study of hip strength in females with patellofemoral pain syndrome, Ireland et al\textsuperscript{16} reported that the females with anterior knee pain demonstrated 26\% less isometric hip abduction strength than the asymptomatic control subjects. In both examples, the authors postulated that females with knee pain or injury may have insufficient hip abduction strength to resist the external abduction moments at the knee during repetitive athletic movements such as the landing, running, and cutting.\textsuperscript{16,18}

Presently, the relationship between proximal hip strength and knee alignment has been largely speculative. Because vertical ground reaction forces in running are the greatest at approximately 45 to 50\% of stance,\textsuperscript{19} it can be postulated that weakness in the gluteus medius may result in greater knee abduction during mid-stance of running as the hip attempts to maintain dynamic control of the limb. This malalignment, coupled with the large ground reaction forces during the stance phase of running, may lead to many of the overuse knee injuries that occur in runners. Therefore, the purpose of this study is to determine if differences in hip abductor strength have an effect on the frontal plane lower extremity knee kinematics during the stance phase of running in healthy females. It was hypothesized that the subjects with weakness in the hip abductors will demonstrate greater knee abduction as compared with the subjects with strong hip abductors.
Methods

One hundred and ten female recreational athletes were recruited from a university campus to participate in this study. A recreational athlete was defined as anyone participating in an aerobic or athletic activity at least 3 times per week. Subjects with any current lower extremity pathology or a history of traumatic or congenital deformity to either lower extremity were excluded. All subjects signed an informed consent form approved by the University of Wisconsin-La Crosse that was in accordance with National Institutes of Health mandated Institutional Review Board guidelines before participation.

Phase One: Hip Abductor Strength Testing

Each subject was asked basic questions regarding their general health status and asked to report on the frequency and intensity of any current aerobic exercise routine using the following descriptors (very active, moderately active, somewhat active, sedentary). Subjects were excluded if they had not been active in some type of regular aerobic exercise program for 30 days. Dominant leg was determined to be the leg each subject would use to kick a ball. Height and mass were measured for each subject using a balanced scale. Hip abductor strength was tested using the Chatillon (Chatillon Force Measurement Systems, Largo, FL) hand-held dynamometer mounted on top of an anchoring station (Figure 1). The testing procedures

Figure 1 — Subject positioned in the testing position for the isometric hip abduction strength using the Chatillon (Chatillon Force Measurement Systems, Largo, FL) anchored dynamometer.
were based on the protocol of Nadler et al., who reported that their hand-held dynamometer mounted on an anchoring system was reliable (intraclass correlation coefficient = .94 to .98) for the measurement of hip extensor and abductor strength. Before the current study, pilot data were collected to determine whether a similar anchored dynamometer would be reliable within a single testing session as well as between testing sessions, using a single examiner. Ten college females of similar age and activity level were tested on two separate testing dates. Data were collected for both right and left hip abductor peak force. Five trials were analyzed to determine the intraclass correlation coefficient (ICC) using SPSS version 12.0 for Windows (SPSS, Inc., Chicago IL) for both a single session (one analysis of the right leg and a separate analysis for the left leg) and two separate sessions 4 to 5 days apart. The reliability for the five trials for the right and left legs for hip abductor peak force was excellent (ICC = 0.98). The reliability of the mean of the five trials between the two sessions was excellent (ICC = 0.98). This indicates that our testing protocol and measurement device is reproducible both within and between days.

In data collection for the current study, the order of limb testing was alternated for each subject. The subjects were instructed to lie down on their left or right side so that their hips were perpendicular to the examination table (Figure 1). While the researcher supported the limb, the dynamometer was positioned approximately 5 cm proximal to the knee joint line with the hip abducted approximately 20 degrees as measured by a handheld goniometer. A position of neutral rotation of the hips was maintained by verbal cuing and positioning of the thigh, leg, and foot parallel to the table. The subjects’ limb was manually brought up to the dynamometer where peak force from each maximal effort was recorded in kilograms. The subjects were instructed to push maximally against the dynamometer for 5 seconds. The subjects were given verbal encouragement throughout each repetition and were observed carefully during the strength testing to ensure that pelvic and hip positioning was controlled. This process was repeated 5 times with a 10 second rest between each effort. The mean of the 5 measurements was obtained and strength was represented as a percentage of each subject’s body mass (Figure 2). The strength values were divided into quartiles and the 15 subjects that exhibited the greatest strength and the 15 that exhibited the least strength returned for a second data collection session where a kinematic assessment of their running pattern was performed.

Phase Two: Kinematic Assessment

The lower extremity kinematic data were captured by placing 15 (25mm) retroreflective markers directly to the skin or spandex clothing using the modified Helen Hayes marker set on each participant (Figure 3). All kinematic data were collected at 240 Hz using 6 JCL (Motion Analysis Corporation, Santa Rosa, CA, USA) cameras positioned at 60° intervals around the performance area within the biomechanics laboratory. The cameras were calibrated producing mean residual errors of 2.10 to 2.53mm over a volume of 3m × 3m × 3m. Based on a frequency content analysis of the digitized coordinate data, marker trajectories were filtered at 10 Hz using a fourth order Butterworth recursive filter. The smoothed marker coordinate data were analyzed using Orthotrak Commercial Software Package (Motion Analysis Corporation, Santa Rosa, CA) and custom Matlab programs (Mathworks Inc., Natick, MA). Segment motions of the pelvis, relative to the laboratory coordinate system, and joint angular position of the hip, knee, and ankle
Figure 2 — Frequency and distribution of hip abduction strength values as a percentage of body mass for all 110 participants. Mean (SD) is 38% (9.36). n = 110. The y-axis represents the frequency of the strength value and the x-axis depicts the mean peak hip abductor strength as a percentage of the subjects’ body mass. The 15 subjects with the weakest hip strength and the 15 subjects with the greatest hip strength were recruited to participate in the kinematic assessment of running.

Figure 3 — Participant with 15 markers applied directly to the skin or spandex clothing in a modified Helen Hayes configuration. Markers on the heel and sacrum are posterior and not shown.
in the sagittal and frontal plane were calculated. By convention and as measured in the sagittal plane, zero degrees at the hip, knee, and ankle corresponds to an erect, standing posture with the trunk, thigh, and lower leg in a straight line and the foot segment at a right angle to the leg. By this convention, the frontal plane hip and knee adduction kinematics were assigned a positive value whereas hip and knee abduction kinematics were assigned negative values, respectively. Similarly in the sagittal plane, hip, and knee flexion was assigned a positive value and hip extension and knee hyperextension a negative value. The angles measured in this study were absolute joint angles. The locations of the hip joint centers were determined from the static capture of the pelvic markers. The hip joint centers were calculated as displacements in the posterior, lateral, and inferior directions and the distances were fixed percentages of the ASIS distance as described by Bush and Gutowski.

Joint centers of the knee and ankle were determined by a static capture with markers on the medial and lateral side of the knee and ankle. A bisection of these marker coordinates was used to calculate the joint centers of the knee and ankle during the running trials.

Subjects were provided with identical pairs of New Balance 629 running shoes to prevent possible variations in lower extremity loading patterns due to differences in footwear. Although each subject reported experience with treadmill running, they were allowed a 3 to 5 min warm-up at a self-selected running speed on the treadmill (Woodway USA, Waukesha, WI) until they felt comfortable with the device and their speed. The speed was then kept constant for each participant (range 1.80 to 3.20 m/s) for seven 3 second trials collected in succession. The treadmill display console and handrails were removed during testing to allow full view of the markers during the running cycle. The stance phase for each trial was determined as the frame that corresponded with the first lowest vertical coordinate of the heel marker and the last vertical coordinate of the toe marker based on visual inspection. Mean maximum and minimum angular measurements were calculated for the frontal and sagittal plane of the hip and knee.

Using SPSS version 12.0 for Windows (SPSS, Inc., Chicago IL), an independent t test with a significance value of $P < .05$ was used to determine if there were demographic differences between the two groups. A series of repeated measures ANOVA (RM ANOVA) with one between factor of group (strong vs. weak hip abductors) and one within factor of time within the stance phase of the running cycle was used. A separate RM ANOVA was used for each joint and plane of motion across each portion of the stance phase (initial contact, maximum position and toe off). A significance value of $P < .05$ was used to determine if these kinematic differences existed during different portions of the stance phase for the knee, hip, and pelvis between the subjects with weak and strong hip abductors.

Results

No significant differences were found in the subject height ($P = .310$), treadmill running speed ($P = .079$), or frequency of aerobic exercise ($P = .522$) between the two groups (Table 1). The only significant demographic difference between the two groups was in the mean body mass ($P = .009$). The group with the stronger hip abductors weighed approximately 10 kg less than the weak hip abductor group.
Overall, no significant differences were found in knee flexion angle \( (P = .827) \), hip flexion angle \( (P = .977) \), hip abduction angle \( (P = .133) \), or pelvic tilt \( (P = .055) \) between the weak and strong hip abductor groups during stance (Table 2). Figures 4, 5, and 6 graphically depict the means and standard deviations of both groups during the stance phase of running for the hip and knee sagittal and frontal planes. Overall, a significant difference was found in the knee abduction angle between the weak and strong hip abductor groups at all portions of the stance phase during treadmill running \( (P = .008) \). Post hoc comparisons indicated differences in knee frontal plane position at initial contact, maximum angle and toe off during the stance phase. Table 2 provides the means and standard deviations for the two groups. Throughout stance, the weak group demonstrated approximately 4° greater knee abduction than the strong group (Figure 7).

**Discussion**

The results of this study indicate that hip abductor weakness may influence the knee abduction angle during the stance phase of running in females. Despite the lack of empirical evidence to support it, a relationship between hip abduction weakness and lower extremity alignment has been generally supported in the literature. Fulkerson\(^{25}\) associated insufficient proximal hip strength with altered lower extremity alignment including femoral adduction, femoral internal rotation, and increased lateral patellar pressure in female athletes. Ireland\(^{15}\) speculated that instability in the core musculature may precede an ACL injury in the female athlete since the
lack of proximal control could contribute to an individual getting into a position of hip adduction, knee abduction and slight flexion, and foot pronation. Based on their study of gender differences in strength and lower extremity kinematics during landing, Lephart et al suggested that further research is needed to explore the relationship between weaknesses and hip and knee stability as it relates to center of gravity and trunk angle during landing. McConnell et al recommended strengthening of gluteal muscles to decrease hip internal rotation during weight bearing activities and lessen the valgus force at the knee.

It is plausible that the kinematic differences between the strong and weak hip abductor groups could predispose the weaker group to a variety of overuse knee injuries. The weak group demonstrated approximately 4° greater knee abduction than the strong group at initial contact and maintained a position of knee abduction throughout most of stance. It is possible that during initial contact through early

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<th>SD (degrees)</th>
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Figure 4 — Time normalized sagittal plane knee range of motion pattern (mean ± 1 SD) during stance phase of running for the weak and strong hip abductor groups. Positive values correspond with knee flexion. Negative values correspond with knee extension.

Figure 5 — Time normalized sagittal plane hip range of motion pattern (mean ± 1 SD) during stance phase of running for the weak and strong hip abductor groups. Positive values correspond with hip flexion. Negative values correspond with hip extension.
Figure 6 — Time normalized frontal plane hip range of motion pattern (mean ± 1 SD) during stance phase of running for weak and strong hip abductor groups. Positive values correspond with hip adduction. Negative values correspond with hip abduction.

Figure 7 — Time normalized frontal plane knee range of motion pattern (mean ± 1 SD) during stance phase of running for the weak and strong hip abductor groups. Positive values correspond with knee adduction. Negative values correspond with knee abduction.
stance, when the tensor facia lata is most active, placement of the knee in relative abduction during a repetitive activity such as running may produce increased tension on the iliotibial band or predispose the knee to abnormal patellar pressures. Frederickson et al reported that runners with iliotibial band syndrome demonstrated significant weakness in the hip abductors. The authors speculated that weakness in the hip abductors may cause an increased valgus vector at the knee resulting in greater tension on the iliotibial band especially during early stance when maximal deceleration occurs to absorb ground reaction forces. Several other investigators have associated the knee abduction angle and moments with the incidence of ACL injury in female athletes. Hewett et al reported that the valgus moment at the knee was the sole significant predictor of peak landing forces. Our investigation did not include peak landing forces or joint moments, but our findings warrant further inquiry into the relationship between hip abductor weakness and knee abduction moments during activities with greater vertical ground reaction forces such as landing.

The knee abduction values in our study were significantly less than those reported by Malinzak et al in their female athletes. Although both studies recruited subjects of similar ages and activity levels, Malinzak et al used a force platform with over ground running, whereas the subjects in the current investigation were measured while running on a treadmill. To date, only one study has examined the frontal plane kinematics of running on different surfaces. Schache et al reported no frontal plane difference in the lumbo-pelvic-hip complex of 10 recreational runners in their kinematic comparison of overground versus treadmill running. Furthermore, our knee abduction values were similar to that of Ferber et al who also used force platform with overground running similar to Malinzak et al. Further investigation may be necessary to determine the influence of running surface on the lower extremity kinematics during running.

The findings of the current investigation may have clinical relevance. Athletes recovering from an overuse injury such as patellofemoral syndrome or iliotibial band tendinitis may benefit from a rehabilitation program that emphasizes dynamic hip stabilization. Further exploration is needed to determine how hip strength asymmetries impact the kinematics and kinetics of athletic movements. As more research is published on this topic, it is plausible that basic hip strength measurements may be useful in determining return to performance guidelines or be used in as a screening tool for clinicians who focus on preventative programming for athletes.

The present investigation has limitations. Strength measurements for the hip external rotators and extensors were not included. Leetun et al reported that cross country runners and collegiate basketball players who did not sustain an injury were stronger in the hip abductors and external rotators than the injured athletes. Their statistical analysis revealed that hip external rotator strength was a useful predictor of injury occurrence. It is unknown whether the subjects with weak hip abductors demonstrated higher peak to body mass ratios in the other hip stabilizers and how that may have influenced the knee kinematics during the stance phase of running.

In addition, the study did not include EMG data. Although significant differences in hip abductor strength values were evident between the strong and weak group, it is unknown if differences existed between the hip activation patterns between the two groups. It is possible that from initial contact into midstance the
weak abductor group had greater recruitment of the tensor fascia lata and iliotibial band as a compensatory strategy for gluteus medius weakness and to control the amount of knee abduction during this time of greatest vertical ground reaction force. Future investigation is warranted to determine if there is a relationship between hip abductor weakness and activation patterns of the hip as it relates to closed chain activities such as running.

It should also be noted that the subjects in the weak group were significantly heavier than the subjects in the strong group. It is possible that these differences in body mass or limb mass could have influenced our results. However, previous studies have demonstrated that joint moments during the stance phase of gait are extremely stable relative to variations in segment inertial parameters for subjects who are of both normal mass and obese. Our participants in the weak group had an average normal body mass index (BMI) that ranged between 24.2 to 28.9 kg/m² and our strong group average BMI were considered in the overmass category that ranged from 20.7 to 22.2 kg/m². It is unknown how this could have influenced the kinematic measures used in the present investigation.

There are also several limitations associated the conventional lower extremity gait model used in this study. The sources of error include accurately placing markers with respect to bony landmarks and the degree of movement of the skin, muscle, and other soft tissue in relation to the bones during movement. It has been suggested that only motion about the flexion/extension axis of the hip, knees, and ankles can be determined reliably. However, most contemporary motion analysis projects are conducted for the purpose of clinical research and not clinical testing to study a condition affecting a group of patients or the effect of an intervention. Therefore, by testing more subjects, even measurements with large random errors can provide meaningful results in clinical research. The marker sets used in this investigation are not vastly different than used in some of these investigations.

**Conclusion**

The results of this study indicate that hip abductor weakness may influence frontal plane knee kinematics during the stance phase of treadmill running. The effect of weakness in additional hip stabilizers such as the hip external rotators and hip extensors on the frontal plane knee kinematics during running warrants further investigation. In addition, future research should include assessment of hip strength as it relates to joint moments during sport-specific activities.

**References**