Sex Differences in Eccentric Hip-Abductor Strength and Knee-Joint Kinematics When Landing From a Jump

Cale Jacobs and Carl Mattacola

Context: Decelerating movements such as landing from a jump have been proposed to be a common mechanism of injury to the anterior cruciate ligament (ACL). Objective: To compare eccentric hip-abductor strength and kinetics of landing between men and women when performing a hopping task. Setting: Research laboratory. Patients: 18 healthy subjects (10 women, 8 men). Main Outcome Measures: Eccentric peak torque of the hip abductors and peak knee-joint angles during a 350-millisecond interval after impact. Results: No significant sex differences were present, but there was a significant inverse relationship between women’s eccentric peak torque and peak knee-valgus angle ($r = –.61$, $P = .03$). Conclusions: Women with larger eccentric peak torque demonstrated lower peak knee-valgus angles. By not reaching as large of a valgus angle, there is potentially less stress on the ACL. Increasing eccentric hip-abductor strength might improve knee-joint kinematics during landing from a jump. Key Words: biomechanics, motion analysis, isokinetic testing

Female athletes have been reported to suffer ACL injuries 2 to 8 times as often as their male counterparts, and 70% to 88% of ACL injuries have been reported to result from noncontact mechanisms. Deceleration, such as landing from a jump, has been proposed to be the most common mechanism of noncontact ACL injuries in female volleyball, basketball, and soccer athletes. Many studies have investigated causative factors that contribute to the increased incidence of ACL injury for females. Risk factors include the following categories: environmental (eg, equipment, surface conditions), anatomic (eg, Q angle, femoral-notch width, ACL laxity), hormonal (eg, concentration of estrogen and progesterone), and biomechanical (eg, muscle strength, lower extremity kinematics, neuromuscular characteristics). Previous protocols have successfully quantified and improved neuromuscular differences between the sexes. Hewett et al implemented a comprehensive lower extremity training program including strength, balance, and plyometric components and reported decreased incidence of ACL tears in female high school athletes. Other protocols have used specific instruction and technique training and have reported biomechanical improvements associated with potentially reduced risk of ACL injury. To our knowledge, however, no studies have assessed...
the relationship of hip-abductor strength with lower extremity kinematics during protocols that mimic noncontact mechanisms of ACL injury.

The hip abductors are active during normal gait to prevent excessive hip adduction and internal rotation and also perform the same function during more dynamic, multiplanar activities such as turning and jumping. Excessive hip motion in these planes might be reduced by improved function of the hip abductors. The intermediate and posterior fibers of the gluteus medius act as both abductors and external rotators of the hip when the hip is flexed less than 20° and, therefore, might limit the magnitude of hip adduction and internal rotation during activity. Decreasing the magnitude of hip adduction and internal rotation has been suggested to reduce the peak angles of knee valgus and external rotation, which have been associated with increased strain on the ACL. Therefore, the purpose of the study was to compare eccentric hip-abductor strength and the kinematics of landing in men and women.

Methods

Subjects

Eighteen healthy, recreationally active adults (10 women, age 22.1 ± 2.3 years, height 167.0 ± 5.0 cm, mass 64.0 ± 8.6 kg; 8 men, age 24.1 ± 2.2 years, height 179.6 ± 3.1 cm, mass 76.2 ± 9.2 kg) volunteered to participate in the study. All subjects had no previous history of lower extremity surgery and had been free from concussion and lower extremity injury during the preceding 6 months. They were also free from any neurological or vestibular disorders that could negatively affect balance.

Instrumentation

Eccentric-strength (peak torque) data were collected using the Biodex System 3 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY; Figure 1). Peak torque values were recorded in ft · lb, converted to N · m, and then normalized to each subject’s body mass (N · m/kg). Strength data were compiled in Microsoft Excel (Microsoft, Inc, Redmond, Wash).

Kinematic data of the knee were collected using 6 Falcon high-speed, high-resolution video cameras (Motion Analysis Corp, Santa Rosa, Calif) at a sampling rate of 120 Hz. Video data were collected and tracked using the Expert Vision Analysis (EVa Real Time 4.1) hardware–software system (Motion Analysis Corp). Data were then smoothed using a fourth-order Butterworth low-pass filter with a cutoff frequency of 6 Hz in EVa RT 4.1 and were then exported into the KinTrak 6.2 (Motion Analysis Corp) software package for further analysis.

Procedures

The protocol was approved by the university’s institutional review board and explained to all subjects. They then signed the informed consent and answered questions regarding their health history to determine eligibility for participation. After a 5-minute warm-up on a cycle ergometer, each subject was prepared for
kinematic-data collection using the Cleveland Clinic marker set. Subjects were then asked to perform 7 trials (3 practice trials, 4 test trials) of a hopping task with the leg they would use to kick a soccer ball.

The hopping task used by this protocol has been previously described by Lephart et al.\textsuperscript{15} Subjects initially stood on the floor with their arms at their sides. Each subject’s starting position was equivalent to 45% of his or her height away from an “X” marked on the floor. A rectangular wooden obstacle (length 61 cm, height 10 cm, width 10 cm) was placed equidistant between the subject’s starting position and the “X.” After a verbal start command, subjects hopped using only 1 leg over the obstacle and landed on the “X” with the same leg used to initiate the hop. After landing, subjects were asked to maintain balance on the hopping leg for approximately 5 seconds. Each subject performed 3 practice trials and 4 test trials. During each trial, peak joint angle (degrees) was recorded for hip flexion (HF), hip adduction (HA), hip internal rotation (HIrot), knee flexion (KF), knee valgus (KV), and knee external rotation (KErot). The peak joint angle was defined as the

\textbf{Figure 1} — Dynamometer positioning for the eccentric strength test of the hip abductors.
maximum angle achieved between initial ground contact and 350 milliseconds after contact. We used the 350-millisecond window in order to ensure that the peak angles being recorded were a direct result of the landing task and not associated with maintaining balance. Lephart et al\textsuperscript{15} reported average time-to-peak-knee-flexion durations of 178 ± 49 milliseconds; therefore, the 350-millisecond window used in our protocol represents 3 standard deviations above this mean value.

After completing the forward hop test, subjects performed a test of eccentric hip-abductor strength. The order of the landing and strength tests was not counterbalanced or randomized, because we did not want subjects to fatigue the hip abductors during strength testing before performing the forward hop. Hip-abductor fatigue has been previously reported to increase knee-valgus angle when landing from a jump.\textsuperscript{16} We understand that the hip abductors might be fatigued during the repetitious performance of the landing task used in this protocol. Nonetheless, we do not believe that 7 repetitions of a submaximal hopping task were enough to elicit significant muscle fatigue. Each trial of the hopping task lasted approximately 6 seconds, and the time required for the subject to return to the starting position, as well as the time required for the authors to prepare the equipment to collect the next trial, was roughly 30 seconds. This creates an estimated 1:5 work:rest ratio. Wadley and Le Rossignol\textsuperscript{17} suggested that a 1:3 ratio is ideal to prevent muscle fatigue when performing repetitive dynamic activities. Because ample rest periods were provided during functional testing, we assumed that the hip abductors would be more fatigued after the maximal eccentric-strength test than after the submaximal hopping task. Because we were testing the relationship of strength to landing kinematics, we did not want individual levels of hip-abductor endurance to increase variability in our results.

Subjects performed the eccentric hip-strength-testing protocol in a standing position. They faced the dynamometer, with the axis of rotation aligned with the hip-joint center. We defined the hip-joint center as the intersection of an imaginary line directed inferiorly from the anterior superior iliac spine down the midline of the thigh and a second imaginary line medially directed from the greater trochanter of the femur toward the midline of the body. Eccentric testing consisted of 2 sets of 5 repetitions: 1 practice set and 1 test set. Subjects were instructed to maintain neutral trunk and pelvis alignment during testing by using their upper body to anchor themselves against a support structure placed in front of the dynamometer (Figure 2). During testing, subjects resisted as the dynamometer moved their leg from a position of 30° of hip abduction to 5° of hip adduction at a velocity of 120°/s. We selected the test velocity of 120°/s in order to replicate the velocity at which the knees of 8 pilot subjects moved into a valgus position when landing from a jump. The average peak torque (PT) of the 5 test trials was recorded and used for further analysis. We have determined the current eccentric-strength protocol to be reliable, with average peak-torque measures resulting in an intraday ICC\textsubscript{2,1} of .89.

### Statistical Analyses

Two-tailed independent \(t\) tests were used to compare PT values between men and women, as well as to test for sex differences in average peak-joint angles for HF, HA, HRot, KF, KV, and KErot. Pearson product–moment correlations were calculated to evaluate the relationship of PT and kinematics of the hip and knee of men and women.
women. An $\alpha$ level of $P \leq .05$ was considered significant. All statistical analyses were performed using SPSS version 12.0 (SPSS, Inc, Chicago, Ill).

## Results

There were no significant differences between sexes for average PT or any of the peak joint angles (Table 1). Although not significant, peak HF, HIrot, and KV angles were larger for women than for men. Moderate effect sizes were present for the peak HF (.68), HIrot (.53), and KV (.62) angles. Average PT values for women were $1.45 \pm 0.35 \text{ N} \cdot \text{m/kg}$ and for men were $1.41 \pm 0.25 \text{ N} \cdot \text{m/kg}$. In men, there were no significant correlations between average PT and the peak joint angles of the hip and knee. There was a significant relationship ($r = .61, P = .03$) between women’s peak KV angle and average PT; however, the relationships between PT and HF, HA, HIrot, KF, and KErot were not significant.

Figure 2 — Subject positioning for the eccentric strength test of the hip abductors.
Increased KV and KErot have been proposed as a common mechanism for ACL injury. In the current investigation there were no significant differences in peak KV and KErot angles between sexes; however, women demonstrated peak KV angles that were 4.43° larger than the peak angles demonstrated by male subjects. The corresponding moderate effect size (0.62) suggests that, although not statistically significant, this result might be meaningful to clinicians. McLean et al reported that when performing a sidestep cutting maneuver, females demonstrated 2° of increased KV. They also stated that a 2° increase in KV might correspond with a 100% (40 N · m) increase in valgus loads. Assuming that our landing task produced vertical ground-reaction forces equal to or greater than those associated with a cutting maneuver, our results suggest that by demonstrating 4.43° of increased KV, women might experience valgus loads roughly 200% greater than their male counterparts, placing them at increased risk of valgus buckling.

Gender differences in KV angle in the current study might be associated with differences in neuromuscular control of the hip, which concurs with results of Zeller et al and McLean et al. These authors have suggested that knee-joint kinematics might be married to neuromuscular control of frontal- and transverse-plane motion of the hip. Our results support their conclusions, because the women in our study demonstrated higher HF and HIrot angles than those of the men. Like KV, the HF and HIrot results were not statistically significant but did result in moderate effect sizes (0.68 and 0.53, respectively).

The association between neuromuscular control of the hip and KV has been previously addressed in the literature. Mansour and Pereira and Delp et al stated that the intermediate and posterior fibers of gluteus medius act as both abductors and external rotators of the hip when the hip is flexed less than 20°. It is interesting that the women in our investigation demonstrated peak HF angles of approximately 23°, compared with 16° angles in the men. The secondary function of the gluteus medius in women might be transitioning into internal rotation when the hip is flexed more than 20°, because women also demonstrated 3.58° greater peak HIrot

Table 1  Peak Joint Angles (Mean ± SD) of the Forward Hop Test

<table>
<thead>
<tr>
<th>Variable</th>
<th>Women</th>
<th>Men</th>
<th>P value</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip flexion</td>
<td>22.78 ± 8.83</td>
<td>15.78 ± 11.06</td>
<td>.15</td>
<td>.68</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>0.36 ± 7.39</td>
<td>2.38 ± 5.38</td>
<td>.53</td>
<td>.31</td>
</tr>
<tr>
<td>Hip internal rotation</td>
<td>3.72 ± 6.39</td>
<td>0.14 ± 7.03</td>
<td>.28</td>
<td>.53</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>50.22 ± 10.47</td>
<td>49.20 ± 8.61</td>
<td>.83</td>
<td>.10</td>
</tr>
<tr>
<td>Knee valgus</td>
<td>14.30 ± 6.66</td>
<td>9.87 ± 7.50</td>
<td>.07</td>
<td>.62</td>
</tr>
<tr>
<td>Knee external rotation</td>
<td>3.98 ± 3.51</td>
<td>5.98 ± 7.81</td>
<td>.48</td>
<td>.35</td>
</tr>
</tbody>
</table>

Comments
than that of the men. Conversely, by staying below 20° of HF, a man’s gluteus medius muscle might be acting as an abductor and external rotator of the hip, thus decreasing strain on the ACL by limiting peak KV and KErot angles. This is supported by the work of Hart et al,21 who reported that gluteus medius activity was significantly larger in males than females performing a forward jump. Males might be activating the gluteus medius muscle at a higher level because it is performing a more beneficial action. The altered function of the primary hip abductor might help explain the potential difference in KV angle between males and females. Gender differences in lower extremity alignment might, in turn, potentially be related to differences in neuromuscular strategies used to attenuate the large forces present when landing from a jump.

There were no significant differences in eccentric PT of the hip abductors between men and women. This is not consistent with previous comparisons of hip strength between sexes. Leetun et al22 reported that, when tested isometrically, males demonstrated greater hip-abduction strength than their female counterparts (males 32.6% ± 7.3% of body weight, females 29.2% ± 6.1% of body weight). Differences in sample population (college athletes vs healthy normal subjects) might potentially explain the differences between the 2 protocols. In a more broad study evaluating isometric hip abduction in subjects between the ages of 20 and 79, however, Bohannon23 reported that men had hip-abduction torque values 19% greater than those of the women. It is unclear whether differences in isometric hip-abductor strength relate to the eccentric results presented in the current study.

Women demonstrated a significant negative correlation between eccentric PT of the hip abductors and peak KV angle, and their male counterparts did not. Some might argue that the magnitude of the correlation \( r = -0.61, r^2 = 0.37 \) might not explain enough of the variability in KV angle to be considered clinically relevant. Nonetheless, when comparing the strength of any single muscle group with the performance of a functional activity that involves the entire lower extremity, such as sprinting and jumping, low correlations can be expected. Wessel et al24 evaluated the individual relationships between strength of the hip abductors and hamstring muscle groups and 50-m sprint times. The resulting correlation of hip-abductor strength \( r = -0.34 \) was similar to that of the hamstrings \( r = -0.38 \), and both values were lower in magnitude than those reported in the current study. Similarly, Ozcakar et al25 compared sprint times with concentric and eccentric strength of the knee flexors and extensors and reported \( r \) values ranging from –0.20 to –0.58. Kea et al26 reported low correlations when isokinetic hip abduction was compared with performance of medial and lateral hop tests.

Average PT explained roughly 37% of the variability in knee-valgus angle in women. It is our contention that, because of the increased strain on the ACL associated with increased KV motion,14 eccentric hip-abductor strength is an extremely important measurement for clinicians. Simply put, women with larger eccentric PT values demonstrated lower peak KV angles. By not reaching as large a KV angle, they are potentially placing less stress on the ACL.18,19,27-29 In addition, it has been previously reported that the ability of the quadriceps and hamstrings to resist forces experienced by the lower extremity when jumping are significantly improved with increased hip-muscle activity.9 The cocontraction between the hip and thigh musculature might allow the quadriceps to more effectively attenuate
the forces associated with landing. If more force is attenuated by the muscles, less force needs to be attenuated by the static stabilizers of the knee. We think that because hip-abductor strength explained over 35% of the variability in KV angle in women, our conclusions support those of Zeller et al\textsuperscript{20} that the hip muscles play an important role in controlling the motion of knee. Eccentric strength of the hip abductors might be important to consider when designing strengthening programs for knee-injury prevention or rehabilitation.

There were several limitations with the current protocol. The strength-testing protocol, which we demonstrated to be reliable (ICC\textsubscript{2,1} = .89), might lack validity. Several subjects commented that the hip abductors of the non-test leg were stressed during testing. In retrospect, the position of the non-test limb, as well as the contraction required to stabilize the hip, might be more closely related to how the hip abductors function when landing from a jump. For example, when testing the right limb of a subject, the left leg was fully weight bearing in a single-leg stance. As the right limb was being forced into adduction by the arm of the dynamometer, the hip abductors of both limbs were being eccentrically loaded. The right limb was being loaded in an open kinetic chain position while the left hip abductors were eccentrically loaded in a closed kinetic chain position. We speculate that the arc of motion, type of contraction, and closed kinetic chain position of the left limb might be more representative of how the hip functions during landing. Unfortunately, we have not developed an accurate, reliable, and valid method for evaluating eccentric strength of the hip abductors in a weight-bearing position, so future research in this area is warranted. Another limitation is that we compared the strength of only 1 muscle group with the kinematics of landing. Future investigations should make the same comparison with the hip abductors and external rotators, hamstrings, and quadriceps muscle groups in order to see how each group relates to the motions of the knee. Finally, this investigation used a small sample population of healthy college-age subjects. The small sample size undoubtedly led to decreased power, which resulted in nonsignificant kinematic results that demonstrated moderate effect sizes. In addition, by evaluating recreationally active adults, we are not able to generalize our results to an athletic population. Future studies might be performed with varied populations including both adolescent and adult athletes. To truly understand the role of the hip abductors in neuromuscular control of the knee, prospective investigations are needed to determine whether inadequate eccentric strength of the hip abductors is associated with increased incidence of ACL injury.

**Conclusions**

There were no significant differences in eccentric strength of the hip abductors or the kinematics of landing between men and women. Women demonstrated a significant relationship between eccentric hip strength and kinematics of the knee. Women with greater eccentric hip-abduction strength had smaller knee-valgus angles when landing from a jump. To potentially improve the position of the knee when landing from a jump, clinicians might want to incorporate exercises that will improve eccentric hip-abductor strength into comprehensive lower-extremity-strengthening programs.
References


