Core Strength and Lower Extremity Alignment during Single Leg Squats

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ABSTRACT

WILLSON, J. D., M. L. IRELAND, and I. DAVIS. Core Strength and Lower Extremity Alignment during Single Leg Squats. *Med. Sci. Sports Exerc.*, Vol. 38, No. 5, pp. 945–952, 2006. **Introduction/Purpose:** Muscles of the trunk, hip, and knee influence the orientation of the lower extremity during weight bearing activities. The purpose of this study was threefold: first, to compare the orientation of the lower extremity during a single leg (SL) squat among male and female athletes; second, to compare the strength of muscle groups in the trunk, hips, and knees between these individuals; and third, to evaluate the association between trunk, hip, and knee strength and the orientation of the knee joint during this activity. **Methods:** Twenty-four male and 22 female athletes participated in this study. Peak isometric torque was determined for the following muscle actions: trunk flexion, extension, and lateral flexion, hip abduction and external rotation, and knee flexion and extension. The frontal plane projection angle (FPPA) of the knee during a 45° SL squat was determined using photo editing software. **Results:** Males and females moved in opposite directions during the SL squat test ($F(1,42) = 5.05$, $P = 0.03$). Females typically moved toward more extreme FPPA during SL squats ($P = 0.056$), while males tended to move toward more neutral alignment ($P = 0.066$). Females also generated less torque in all muscle groups, with the exception of trunk extension. The projection angle of the knee during the SL squat test was most closely associated with hip external rotation strength. **Conclusion:** Using instruments suitable for a clinical setting, females were found to have greater FPPA and generally decreased trunk, hip, and knee isometric torque. Hip external rotation strength was most closely associated with the frontal plane projection angle. **Key Words:** GENDER, KNEE, HIP ROTATION, WEIGHT BEARING

Differences in lower extremity mechanics between males and females during weight bearing are believed to contribute to the gender bias for ACL injury and patellofemoral pain (PFP). For example, during single leg cross-cutting maneuvers, the orientation of the knee for males has been shown to begin in valgus and move toward varus alignment (18). Conversely, the female knee began in valgus and moved toward further valgus during the same task. In the transverse plane, studies suggest females display significantly greater hip internal rotation and tibial external rotation than males during running and single leg landings (6,15). These differences may contribute to the above gender bias as tibial abduction with external rotation is believed to strain the ACL against the lateral femoral trochlea (8). Further, knee external rotation is associated with increased lateral retropatellar contact pressure, a commonly accepted risk factor for PFP (13).

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While it is generally accepted that female athletes demonstrate movement patterns different from men, there exists considerable debate regarding the reason for these differences. Several authors have hypothesized that females are prone to these movement tendencies due to decreased neuromuscular control of knee joint musculature and associated decreased knee joint stiffness (7,29). Markolf et al. (20) reported that voluntary contraction of all muscles crossing the knee joint can decrease the frontal plane laxity of the knee threefold. Wojtys et al. (29) reported that female athletes who participate in jumping and cutting sports demonstrate decreased ability to resist tibial torsion loads than age- and activity-matched males. Finally, Hewett (9) attributed the observed reduction in frontal plane knee moments for females who participated in neuromuscular training program to increased strength and activity of the knee flexors while landing.

Hip strength and neuromuscular control differences between males and females may also significantly impact frontal and transverse plane knee moments (22). Using a planar three-link model of the lower extremity, the axial force necessary to cause the knee to buckle in the frontal plane was particularly sensitive to the level of hip muscle stiffness (3). Further, females have been reported to absorb significantly less energy with their hip musculature than males during landing, which suggests that females may generate less hip stiffness than males (5). Together, these two studies suggest that females have potential for greater frontal plane knee motion during weight-bearing activities. Indeed, Hurd et al. (11) recently reported greater knee abduction and hip internal rotation excursion and excursion rate in females compared with males in both normal and perturbed walking conditions. These results support the concept of greater eccentric demands on the hip abductors and external rotators in females versus males previously described during running (6). Finally, Leetun et al. (14) reported that female athletes who participated in running and jumping sports were significantly weaker in hip abduction, external rotation, and lateral trunk flexion than their male counterparts. Those athletes who demonstrated the greatest weakness in hip external rotation were most likely to experience an injury over the course of their sport season.

The above literature indicates females may place greater demands on hip musculature during weight bearing, but possess decreased capacity to generate muscular stiffness. Therefore, it is reasonable to conceive of a situation for lower extremity injury involving excessive hip internal rotation and knee abduction. Indeed, females with the greatest initial and peak knee abduction angles and moments during the stance phase of landing have been found to be most likely to experience an ACL injury during their sport season (10).

Given this evidence, it appears prudent to screen athletes for three-dimensional (3D) knee alignment during weight-bearing activities to identify individuals with a predisposition for injury. Unfortunately, at this time, determination of reliable 3D kinematics typically requires resources that are not practical for a clinical setting. Perhaps because of this limitation, two-dimensional (2D) techniques using more readily available instruments have been investigated. For example, using a digital video camera, frontal plane projection angles (FPPA) of the knee were recorded for males and females during cutting and compared with 3D lower extremity kinematics recorded simultaneously (24). The results of this study reveal that although the FPPA is inherently influenced by transverse plane excursions, it accounts for a significant proportion of the variance in the 3D tibiofemoral abduction angle. The authors concluded that despite the limitations of a 2D approach, it can be a useful estimate of knee valgus during weight-bearing activities.

A very simple test of knee alignment during weight bearing commonly performed in a clinical setting is the single leg (SL) squat test. Using this test, Zeller (31) recently reported increased knee valgus and increased quadriceps muscle activity in females compared with males. The authors concluded that the increased quadriceps activity was not effective at preventing frontal plane knee movement. Instead, the authors suggest that the females in this study demonstrated increased knee valgus due to decreased hip muscle control. Therefore, it was suggested that this test may be effective for screening athletes for knee valgus during weight bearing due to decreased hip stability during athletic tasks. However, the contribution of muscles that may influence knee valgus angles during weight bearing, including muscles of the trunk, hip, and knee, has yet to be determined.

A practical means to document lower extremity alignment during the SL squat test has not been reported. However, 2D methods are typically portable, inexpensive, and readily accessible to practicing clinicians. Further, 2D analysis of lower extremity alignment is associated with 3D knee valgus (24), and 3D knee valgus is associated with injuries such as PFP and ACL rupture (10). Therefore, a 2D estimate of lower extremity alignment during the SL squat test may be a useful clinical measure.

The purpose of this study was threefold. First, we aimed to compare the orientation of the lower extremity between males and females during the SL squat test using procedures and equipment that were suitable for a clinical environment. Second, we aimed to compare isometric strength of the trunk, hip, and knee musculature in males and females using a similar clinical, yet reliable approach. Third, we aimed to determine the extent to which the strength of muscles in the trunk, hip, and thigh are associated with the orientation of the lower extremity during the SL squat test. Based on available literature, we hypothesized that females would demonstrate greater knee frontal plane projection angles and decreased trunk, hip, and knee strength. Finally, we believed that hip strength measures would be most closely associated with the orientation of the knee during the SL squat test.

METHODS

Based on pilot data and estimates of sample variability available in the literature (14), we estimated that 20 subjects per group would be necessary to identify a 15% difference between males and females for all dependent variables at $\alpha = 0.05$ and $\beta = 0.20$. Therefore, we recruited 46 athletes (24 male, 22 females) who were actively involved in preseason conditioning for Division 1A or 1AA basketball, soccer, or volleyball (Table 1). To confirm that there would be no gender bias with respect to current activity level, all athletes rated their current activity level using the Tegner scale. The Tegner activity rating scale uses a 10-level ordinal scale to classify sports participation and occupational activities. Subjects were excluded if they reported any lower extremity surgery within the last 6 months or any current back or lower extremity pain or injuries. No subject reported a history of surgery for knee ligament repair. Each subject read and signed a written informed consent before testing. The study protocol was approved by the institutional review board of the University of Delaware.

Peak isometric torque was calculated for the following muscle groups: trunk extensors, trunk flexors, trunk lateral flexors, hip abductors, hip external rotators, knee flexors, and knee extensors. All test positions were based on those identified in the literature and were gravity-resisted. Straps were used to stabilize the subject and handheld dynamometer (Lafayette Instruments, Lafayette, IN) to eliminate the

TABLE 1. Average subject demographics (standard deviation of the mean in parenthesis).

	Age (yr)	Height (m)	Weight (kg)	Activity Level
Males	19.9 (2.3)	1.83 (0.10)	79.8 (10.4)	9.8 (0.7)
Females	19.4 (0.7)	1.72 (0.07)	66.0 (6.4)	9.8 (0.4)

Activity level was determined using the Tegner activity scale. Participation in competitive sports that require jumping, cutting, and hard pivoting 4–7 $d{\cdot}wk^{-1}$ at the varsity team or professional level corresponds to an activity rating of 10 out of 10.

influence of tester strength on these measurements. The force plate of the handheld dynamometer measured 3 cm by 7 cm and was covered in 0.5 cm of neoprene for comfort during contractions. For each test, two practice and three experimental trials were performed for 5 s with 15 s of rest between contractions. The average of the peak torque values produced during these three trials for each muscle group was used for analysis. All measures were taken on the dominant leg (determined according to which leg the athlete would choose to kick a ball as hard as possible (4).

Segment lengths were determined to convert the force measurements of the handheld dynamometer to units of torque. Torque is defined as the product of the component of force that is perpendicular to the lever arm and the length of the lever arm from the pivotal axis to the point where the force is applied. Therefore, the length of the lever arm to the point of the application of the force was recorded for each subject. The abdominal muscle lever arm was defined as the distance between the midpoint of the ASIS to the sternal notch. The trunk extensor lever arm was the distance between the midpoint of the PSIS to midpoint of inferior angle of the scapula (with arms overhead). The lever arm for the side bridge test, used to gauge quadratus lumborum strength, was the distance from the lateral malleolus to the ipsilateral iliac crest. The lever arm for the external rotators and hip abductors was the distance from the lateral malleolus to the lateral femoral condyle and greater trochanter, respectively.

Trunk flexion. The procedures for isometric trunk flexion strength testing were based on those described by Magnusson et al. (17). The athletes were positioned supine on a treatment table with their hands behind their head and feet secured to the table with a stabilization strap holding their legs in 90° of knee flexion. The dynamometer was placed such that the center of the force pad was 1 inch below the sternal notch. A second strap was placed over the dynamometer and around the underside of the table. Instructions for the athlete were to lift their trunk upward with maximal effort. The test–retest reliability of the force measurements (ICC equation 3,1) for this measure was determined to be 0.87.

Trunk extension. Isometric trunk extension strength test procedures were also based on those described by Magnusson et al. (17). The athletes were positioned prone on a treatment table with their hands behind their head and distal thighs secured to the table with a stabilization strap. The dynamometer was placed such that the center of the force pad bisects a line connecting the superior/medial angle of the athlete's scapulae. A strap was then secured over the dynamometer and around the underside of the table. To limit the contribution of hamstring activity on trunk extension strength, the athlete's feet were supported on a bolster in 30° of knee flexion. Instructions for the athlete were to lift their trunk upward with maximal effort. The test–retest reliability of the force measurements (ICC equation 3,1) for this measure was determined to be 0.85.

Lateral trunk flexors. Isometric strength testing of lumbar lateral flexors was based on the test position described by McGill et al. (23). The athletes were positioned on the treatment table on the side of their dominant leg with both legs extended. The top foot was placed in front of the bottom foot for support during testing. The dynamometer was secured to the subject such that the center of the force pad was directly underneath the lateral iliac crest of the top leg. The athletes were then asked to lift their hips off the table and assume a straight

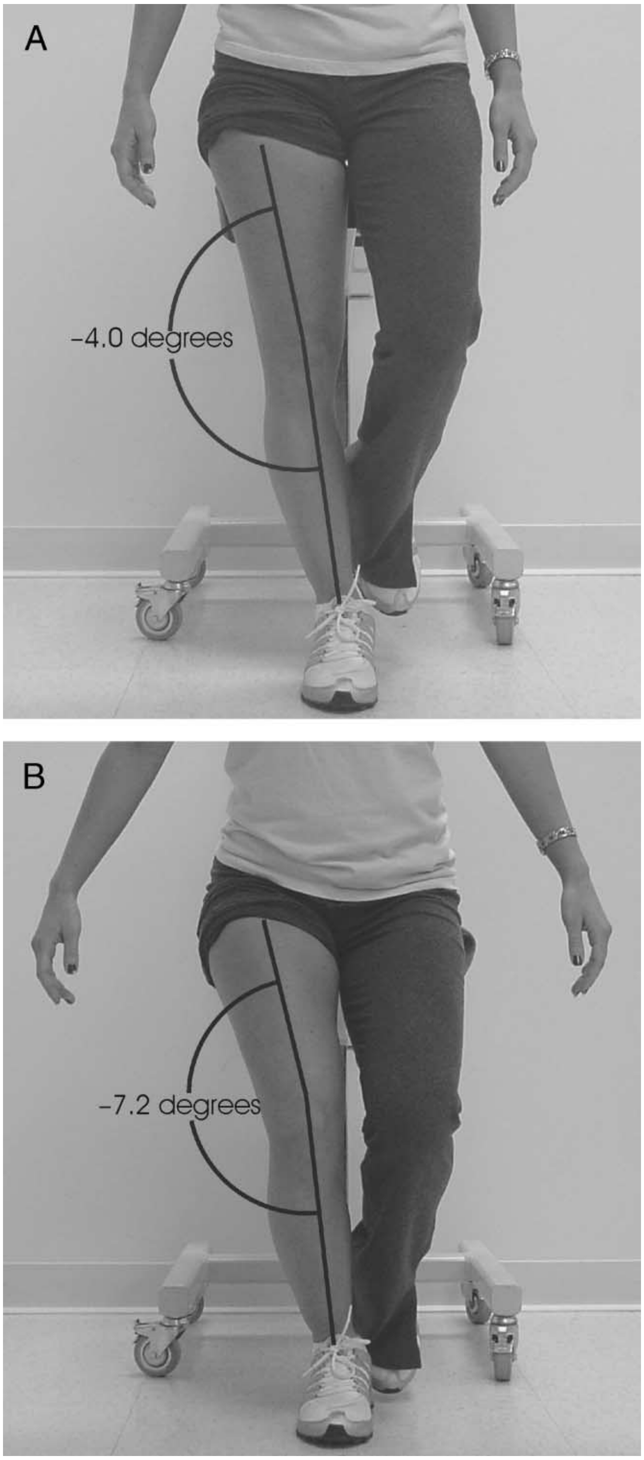

FIGURE 1—Measurement of the FPPA during A) single leg stance and B) single leg squat.

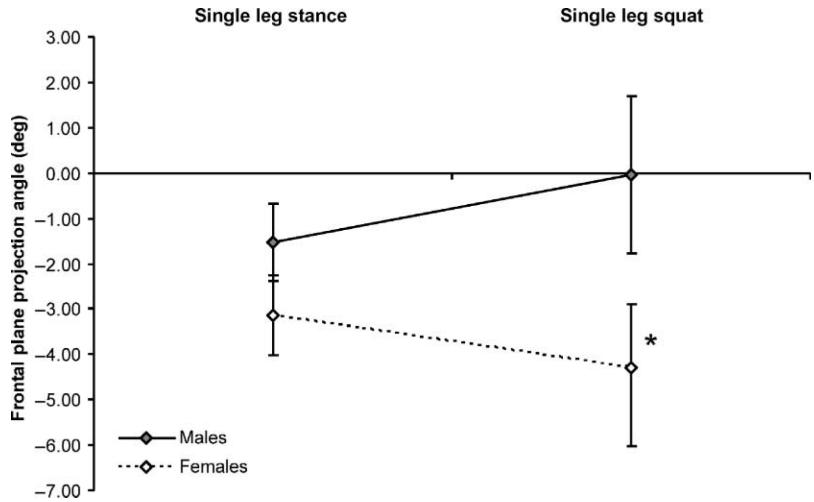

FIGURE 2—Average FPPA for males and females in single leg stance and squat positions. ***Error bars*** **represent 95% confidence intervals of the mean. * Significant gender × position interaction, P < 0.05.**

line over their full body length, supporting themselves on one elbow and their feet. The uninvolved arm was held across the chest with their hand placed on their opposite shoulder. Once the subject assumed the test position, a second strap was secured around the dynamometer and around the underside of the table. Instructions for the athlete were to lift their hips upward with maximal effort. The test–retest reliability of the force measurements (ICC equation 3,1) for this measure was determined to be 0.97.

Hip abduction. Isometric strength testing procedures for hip abduction were based on those described by Bohannon (1). For isometric testing of hip abduction strength, the athlete was positioned to lie on his or her side on a treatment table. The dynamometer was placed on the lateral thigh at a point 2 inches proximal to the lateral knee joint line. A large pillow was placed between the athlete's legs, using additional toweling as needed, such that both hips were in 0° abduction with respect to a line connecting the right and left ASIS. A strap placed just proximal to the iliac crest and secured firmly around the underside of the table stabilized the athlete's trunk. The center of the force pad of the handheld dynamometer was then placed directly over the mark located just above the knee joint. The dynamometer was secured to the leg using a second strap that was wrapped around the leg and the underside of the table. Instructions for the athlete were to lift their top leg upward with maximal effort. The test–retest reliability of the force measurements (ICC equation 3,1) for this measure was determined to be 0.95.

Hip external rotation. Isometric strength testing procedures for hip external rotation were based on those described by Cahalan et al. (2). The athletes were seated on the treatment table with the hips and knees flexed to 90°. A strap was wrapped around the thighs of the athlete and around the underside of the treatment table. A towel roll was also placed between the athletes' knees to maintain knee position and minimize the contribution of the hip adductors to force production in rotation. The dynamometer was placed such that the center of the force pad was directly over a mark 2 inches proximal to the medial malleolus of the test leg. A strap in line with the distal shank and the base of the treatment table held the dynamometer in place during contractions. Instructions for the athlete were to rotate his or her leg into the dynamometer with maximal effort. The test–retest reliability of the force

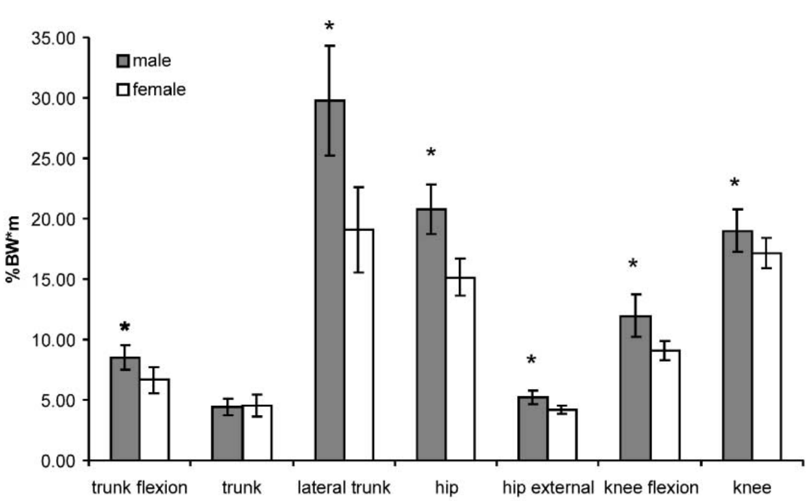

FIGURE 3—Average isometric torque for males and female athletes. ***Error bars*** **represent 95% confidence intervals of the mean. * Significant difference between males and females, P < 0.05.**

measurements (ICC equation 3,1) for this measure was determined to be 0.83.

Knee flexion. The procedures for isometric knee flexion strength measurements were based on those previously described by Worrell (30). Athletes were positioned prone on the treatment table with their pelvis secured to the table with a stabilization strap. The feet of the subject were placed on a firm bolster so that the knees were flexed to 30°. The center of the dynamometer was placed 1 inch proximal to a line connecting the malleoli on the posterior aspect of the athlete's lower leg. A second stabilization strap around the leg of the treatment table was used to provide resistance and to hold the dynamometer in place during contractions. Instructions for the athlete were to flex their knee with maximal effort. Worrell (30) previously reported the test–retest reliability of the force measurement for this measure (ICC equation 2,1) to be 0.93.

Knee extension. The procedures outlined for testing knee extension strength were based on those previously described by Walsworth et al. (28). The athletes were positioned supine on a treatment table with a firm bolster behind the knee of the tested limb so that the knee was flexed to 30°. The athletes were positioned so that the malleoli were at the edge of the treatment table. The opposite lower extremity was flexed so that the foot was on the treatment table. The athlete's arms were crossed on their chest. The dynamometer was placed such that the center of the force pad was 1 inch proximal to a line connecting the malleoli of the leg to be tested. A strap around the leg of the treatment table was used to apply resistance and to hold the dynamometer in place during contractions. Instructions for the athlete were to extend their knee with maximal effort. Walsworth (28) previously reported the test–retest reliability of the force measurement for this measure (ICC equation 3,1) to be 0.96.

SL squat test. SL squats were performed by each subject for analysis of the frontal plane projection angle of the knee. Marks were placed on the leg of each subject on the proximal thigh (along a line between the ASIS and midpoint of the tibiofemoral joint), at the midpoint of the tibiofemoral joint, and at the midpoint of the ankle mortise. Subjects were instructed to stand with the contralateral limb off the floor and their toes forward while a digital image was recorded representing the anatomical alignment in single limb stance (Fig. 1). To obtain this image, a digital camera was placed on a tripod at a distance of 2 m, at the height of the knee joint, and perpendicular to the frontal plane of the subject. An adjustable stool was placed behind the subject at a height that represented the distance from the floor each subject would need to assume to achieve 45° of knee flexion. Subjects were asked to squat on the interested leg until they lightly touched the stool with their seat. In this position, a second digital image was recorded. The digital images were imported into a digitizing software program (CorrelDraw, Chicago, IL). The angle subtended between the line formed between the markers on the proximal thigh and middle of the tibiofemoral joint and that formed from the markers on the middle of the tibiofemoral joint to the middle of the ankle mortise was recorded as the FPPA of the knee. This value is different than the measurement of the quadriceps angle. The knee marker was placed without regard to the patella and the distal marker was not associated with the tibial tuberosity. The average FPPA value from three trials was used for analysis. Within-day reliability testing of this method resulted in an ICC value (model 3,k) of 0.88.

Statistics. Analysis of the SL squat test was performed using a mixed-factor ANOVA (gender × position) (SPSS 13.0, Chicago, IL). Paired *t*-tests were used to examine simple effects in the case of a significant interaction. All seven average isometric torque measurements were analyzed using a MANOVA. Univariate ANOVA were performed for each dependent variable included in the MANOVA if necessary. The association between the isometric strength measurements and SL squat knee angle was analyzed using Pearson correlation coefficients. The significance level was set at $P < 0.05$ for all tests. Observations were evaluated for the presence of outliers using the Extreme Studentized Deviate (ESD) statistic (27). Those observations with an ESD statistic greater than the ESD critical value ($ESD_{24,95} = 2.8$) were considered outliers and were subsequently removed from the analysis.

RESULTS

Examination of the data for each variable revealed two male outliers, resulting in analysis of 22 male and 22 female athletes. The mixed-factor ANOVA revealed a significant gender × position interaction ($F(1,42) = 5.05$, $P = 0.03$) for the FPPA during the SL squat test (Fig. 2). Follow-up paired *t*-tests of FPPA within gender indicated that females typically moved toward more extreme FPPA during SL squats ($P = 0.056$), while males tended to move toward more neutral alignment ($P = 0.066$).

The MANOVA test statistic (Hotelling's T^2) revealed that females produced different results than males when all strength measurements were considered together ($F = 2.92$, $P = 0.016$). Follow-up tests indicate that females generated markedly less torque in all muscle groups with the exception of trunk extension (Fig. 3). As expected, each strength measure was directly associated with the FPPA.

TABLE 2. Pearson correlation coefficients and *P* values for the association between core strength measures and the single leg squat frontal plane projection angle.

		Trunk Flexion	Trunk Extension	Trunk Lateral Flexion	Hip Abduction	Hip External Rotation	Knee Flexion	Knee Extension
FPPA	r	0.03	0.26	0.27	0.23	0.40	0.33	0.18
	P	0.42	0.05	0.04	0.07	0.004	0.02	0.12

However, the FPPA of the knee was most closely associated with hip external rotation strength (Table 2).

DISCUSSION

The first intent of this study was to investigate differences between males and females with respect to the orientation of the knee joint during a SL squat. The results of this study suggest that males and females tend to move in opposite directions during the SL squat test. These 2D results are consistent with studies that utilized more sophisticated motion analysis. For example, using an eight-camera, high-speed motion analysis system, Ford (7) reported that females displayed greater initial and peak knee valgus angles during a vertical drop/jump maneuver compared with males. Further, Zeller (31) reported higher knee valgus angles in females than males during the SL squat test. Finally, Malinzak (18) reported that males and females both began a SL cross-cutting maneuver with a valgus knee orientation. Further, similar to the results of the present study, the females in Malinzak's study moved toward greater valgus while males' knees moved toward varus alignment during the maneuver.

Gender differences with respect to neuromuscular control, anatomy, and strength have typically been linked to the above kinematic variations. It is likely that a combination of these factors also contributed to the results of the present study. For example, although not directly measured as part of this project, differences in pelvic width to femoral length ratios traditionally observed between males and females suggests that females stand in greater tibiofemoral valgus (22). Therefore, the females in this study may have moved toward more extreme FPPA because they began the movement with greater FPPA.

To the extent of the association between the FPPA and tibiofemoral valgus, the SL squat test holds potential to screen for individuals with a propensity for mechanics thought to stress the ACL. Recently, it was reported that the FPPA is significantly correlated with the 3D knee abduction angle during the stance phase of side step and side jump maneuvers (24). Knee abduction angle is a major contributor to the variability of knee valgus moments during weight-bearing activities, and valgus moments are reported to increase the strain on the ACL (19). However, further studies are necessary to investigate the extent to which an individual's kinematics during SL squats represent those during more provocative activities.

To the extent of the association between the FPPA and Q angle, the SL squat test also holds potential to screen for individuals with a propensity for high retropatellar contact pressure. Several cadaver studies have demonstrated a direct correlation between Q angle and retropatellar contact pressure. For example, using simulated muscle loads, Li et al. (16) demonstrated that a small increase in femoral internal rotation increased peak contact pressure of the PF joint 10–24% at every 30° interval of knee flexion. Intuitively, joint rotations that tend to increase the Q angle such as hip internal rotation and tibiofemoral valgus should also increase the FPPA. Further studies are necessary to determine the extent of the association between the Q angle and the FPPA during the SL squat test as well as during more dynamic activities.

The second purpose of this study was to compare the isometric strength of trunk, hip, and knee muscles between males and females using a similar clinical approach. For every muscle group except for the lumbar extensors, females demonstrated lower average isometric torque values than males. Previous studies suggest that females possess greater endurance of the lumbar extensors (23). However, because females possess a relatively smaller erector spinae cross-sectional area compared with males, we expected greater trunk extension isometric torque among male athletes (21). Perhaps males had a greater proportion of body weight in their trunk than females and subsequently produced relatively less torque against gravity during this test than other strength tests.

The remainder of our results with respect to peak torque is in agreement with previous studies using isokinetic dynamometry. For example, Lephart (15) reported lower knee flexion and extension peak torque to body weight at $60°\cdot s^{-1}$ in Division I female athletes compared with a male control group matched for age and activity level. With respect to the hip, Cahalan et al. (2) used a stabilization frame attached to a Cybex dynamometer and reported greater isometric and isokinetic strength in all planes of the hip in males versus females of similar ages. Finally, a study of peak isometric torque of the trunk flexors and extensors in healthy males and females by Keller et al. (12) revealed that females produce significantly less torque than males in a variety of trunk positions as determined with a trunk dynamometer. While the methods employed in previous studies offer some unique advantages to handheld dynamometry, we believe that the strength measurement techniques used in this study are more conducive to offsite examinations and screening a large number of people. Further, with practice, the strength tests have good reliability and the necessary equipment is readily available to practicing clinicians.

The relationship between muscular strength and risk for lower extremity injury is not fully understood. However, several prospective studies suggest that athletes with decreased strength in particular muscle groups are more prone to injury. For example, Leetun (14) recently reported that basketball and track athletes with lower strength values in hip external rotation and hip abduction were more likely to suffer an injury over the course of the season. Decreased strength in hip abduction and adduction has also been associated with an increased incidence of groin injuries among rugby league players (25). Additionally, with respect to the knee joint, Orchard (26) reported that preseason knee flexion weakness was a risk factor for hamstring strains in Australian rules football. Taken together, these studies suggest that lower extremity injury prevention for athletes requires, at least, a measure of hip and knee strength prior to participation. The instruments and methods described in this study appear suitable for such a purpose.

The third aim of the present study was to determine the extent to which the strength of muscles in the trunk, hip, and thigh are associated with the orientation of the lower extremity during a SL squat. Though the correlation coefficients between strength measures and the FPPA were generally small, the association between hip external rotation strength and FPPA was both clinically and statistically significant. Due to the 2D nature of the FPPA, it is sensitive to motion in both the frontal and transverse planes. Therefore, athletes who squat with greater hip internal rotation are likely to demonstrate more negative FPPA values. The relationship between hip external rotation strength and the FPPA in this study suggests that subjects with greater hip external rotation strength may have been better suited to resist hip internal rotation moments. Greater capacity to resist these moments may result in smaller hip internal rotation angles during the SL squat and FPPA values closer to zero.

Although further study is required to validate the SL squat test as a measure of lower extremity alignment during weight-bearing activities, this test holds promise as a clinical measure. For instance, it is conceivable that clinicians may use this test to objectively document changes in lower extremity alignment within a patient as they progress through rehabilitation for return to jumping or cutting sports. Additionally, the equipment for this test is portable, inexpensive, generally reliable, and readily available to practicing clinicians. Therefore, after further validation, this test may be suitable to screen a large number of people in order to identify individuals with a propensity for increased TF valgus angles. Additional studies may also consider whether those people with greater FPPA values during a SL squat also demonstrate greater FPPA values during more athletic weight-bearing activities. Finally, prospective studies are necessary to determine whether measurement of the FPPA during a SL squat has value with respect to an athlete's risk for injury over the course of a sport season.

CONCLUSION

Using instruments and methods suitable for a clinical environment, this study demonstrates that females move toward greater frontal plane projection angles than males during SL squats. Additionally, females generated lower trunk, hip, and knee torque versus males. Hip external rotation torque correlated most significantly with FPPA values.

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REFERENCES

1. BOHANNON, R. Reference values for extremity muscle strength-obtained by hand-held dynamometry from adults aged 20 to 79. *Arch. Phys. Med. Rehabil.* 78:26–31, 1997.
2. CAHALAN, T. D., M. E. JOHNSON, S. LIU, and E. Y. CHAO. Quantitative measurements of hip strength in different age groups. *Clin. Orthop.* 246:136–145, 1989.
3. CHAUDHARI, A., D. CAMARILLO, B. HEARN, L. LEVEILLE, and T. ANDRIACCI. The mechanical consequences of gender differences in single limb alignment during landing. *J. Orthop. Sports Phys. Ther.* 33:A24–A25, 2003.
4. COREN, S., C. PORAC, and P. DUNCAN. A behaviorally validated self-report inventory to assess four types of lateral preference. *J. Clin. Nueropsych.* 1:55–64, 1979.
5. DECKER, M. J., M. R. TORRY, D. J. WYLAND, W. I. STERETT, and J. R. STEADMAN. Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clin. Biomech. (Bristol, Avon)* 18:662–669, 2003.
6. FERBER, R., I. M. DAVIS, and D. S. WILLIAMS III. Gender differences in lower extremity mechanics during running. *Clin. Biomech.* 18:350–357, 2003.
7. FORD, K. R., G. D. MYER, and T. E. HEWETT. Valgus knee motion during landing in high school female and male basketball players. *Med. Sci. Sports Exerc.* 35:1745–1750, 2003.
8. FUNG, D. T., and L. Q. ZHANG. Modeling of ACL impingement against the intercondylar notch. *Clin. Biomech. (Bristol, Avon)* 18:933–941, 2003.
9. HEWETT, T., T. LINDENFELD, J. RICCOBENE, and F. NOYES. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am. J. Sports Med.* 27:699–706, 1999.
10. HEWETT, T. E., G. D. MYER, K. R. FORD, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am. J. Sports Med.* 33:492–501, 2005.
11. HURD, W. J., T. L. CHMIELEWSKI, M. J. AXE, I. DAVIS, and L. SNYDER-MACKLER. Differences in normal and perturbed walking kinematics between male and female athletes. *Clin. Biomech. (Bristol, Avon)* 19:465–472, 2004.
12. KELLER, T. S., and A. L. ROY. Posture-dependent isometric trunk extension and flexion strength in normal male and female subjects. *J. Spinal. Disord. Tech.* 15:312–318, 2002.
13. LEE, T. Q., B. Y. YANG, M. D. SANDUSKY, and P. J. MCMAHON. The effects of tibial rotation on the patellofemoral joint: assessment of the changes in in situ strain in the peripatellar retinaculum and the patellofemoral contact pressures and areas. *J. Rehabil. Res. Dev.* 38:463–469, 2001.
14. LEETUN, D. T., M. L. IRELAND, J. D. WILLSON, B. T. BALLANTYNE, and I. M. DAVIS. Core stability measures as risk factors for lower extremity injury in athletes. *Med. Sci. Sports Exerc.* 36: 926–934, 2004.
15. LEPHART, S., C. FERRIS, B. RIEMANN, J. MEYERS, and F. FU. Gender differences in strength and lower extremity kinematics during landing. *Clin. Orthop. Rel. Res.* 401:162–169, 2002.
16. LI, G., L. DEFRATE, S. ZAYONTZ, S. PARK, and T. GILL. The effect of tibiofemoral joint kinematics on patellofemoral contact pressures under simulated muscle loads. *J. Orthop. Res.* 22: 802–806, 2004.
17. MAGNUSSON, S., N. CONSTANTINI, M. MCHUGH, and G. GLEIM. Strength profiles and performance in masters' level swimmers. *Am. J. Sports Med.* 23:626–631, 1995.
18. MALINZAK, R. A., S. M. COLBY, D. T. KIRKENDALL, B. YU, and W. E. GARRETT. A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin. Biomech. (Bristol, Avon)* 16:438–445, 2001.
19. MARKOLF, K., D. BURCHFIELD, M. SHAPIRO, M. SHEPARD, G. FINERMAN, and J. SLAUTERBECK. Combined knee loading states that generate high anterior cruciate ligament forces. *J. Orthop. Res.* 16:930–935, 1995.

20. Markolf, K. L., A. Graff-Radford, and H. C. Amstutz. In vivo knee stability. A quantitative assessment using an instrumented clinical testing apparatus. *J. Bone Joint Surg. Am.* 60:664–674, 1978.
21. Marras, W. S., M. J. Jorgensen, K. P. Granata, and B. Wiand. Female and male trunk geometry: size and prediction of the spine loading trunk muscles derived from MRI. *Clin. Biomech. (Bristol, Avon)* 16:38–46, 2001.
22. McClay-Davis, I., and M. L. Ireland. ACL research retreat: the gender bias. April 6–7, 2001. Meeting report and abstracts. *Clin. Biomech. (Bristol, Avon)* 16:937–959, 2001.
23. McGill, S. M., A. Childs, and C. Liebenson. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch. Phys. Med. Rehabil.* 80:941–944, 1999.
24. McLean, S. G., K. Walker, K. R. Ford, G. D. Myer, T. E. Hewett, and A. J. van den Bogert. Evaluation of a two dimensional analysis method as a screening and evaluation tool for anterior cruciate ligament injury. *Br. J. Sports Med.* 39:355–362, 2005.
25. O'Connor, D. Groin injuries in professional rugby league players: a prospective study. *J. Sports Sci.* 22:629–636, 2004.
26. Orchard, J., J. Marsden, S. Lord, and D. Garlick. Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *Am. J. Sports Med.* 25:81–85, 1997.
27. Rosner, B. A. *Fundamentals of Biostatistics*. Pacific Grove, CA: Duxbury, 2000,pp. 300–306.
28. Walsworth, M., R. Schneider, J. Schultz, et al. Prediction of 10 repetition maximum for short-arc quadriceps exercise from hand-held dynamometer and anthropometric measurements. *J. Orthop. Sports Phys. Ther.* 28:97–104, 1998.
29. Wojtys, E. M., L. J. Huston, H. J. Schock, J. P. Boylan, and J. A. Ashton-Miller. Gender differences in muscular protection of the knee in torsion in size-matched athletes. *J. Bone Joint Surg. Am.* 85-A:782–789, 2003.
30. Worrell, T. W., G. Karst, D. Adamczyk, et al. Influence of joint position on electromyographic and torque generation during maximal voluntary isometric contractions of the hamstrings and gluteus maximus muscles. *J. Orthop. Sports Phys. Ther.* 31:730–740, 2001.
31. Zeller, B. L., J. L. McCrory, W. B. Kibler, and T. L. Uhl. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Am. J. Sports Med.* 31:449–456, 2003.