[Athletic Training]

Sex Differences in Knee Abduction During Landing: A Systematic Review

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Background: Females suffer injuries to the anterior cruciate ligament at rates significantly higher than males. Frontal plane knee motion and load have been identified as major risk factors for anterior cruciate ligament injury and in turn have been examined extensively.

Methods: A systematic review of MEDLINE, CINHAL, and SportDISCUS was performed (1982–June 2010). Criteria for inclusion were the use of 3-dimensional analyses of frontal plane knee motion and moments during landing between males and females.

Results: Twenty-seven studies met the inclusion criteria and were reviewed. Sixty-three percent of included studies identified sex differences in knee abduction when landing across a variety of landing conditions.

Conclusions: Females appear to land with increased knee abduction motion compared with males in most biomechanics studies.

Keywords: sex differences; anterior cruciate ligament; valgus; knee injury risk

Since the inception of Title IX in 1972, female participation in sports has increased dramatically. Consequently, this has led to an increase in overall sports-related injuries in females. Lower extremity injuries are common in sports, totaling approximately 60% of all collegiate basketball injuries.[2] Specifically, females suffer a higher risk of anterior cruciate ligament (ACL) injuries than males.[30] The majority of ACL injuries occur by noncontact mechanisms, including cutting, pivoting, and landing from a jump.[1,3,18] Altered movement patterns can be described by the specific plane in which the majority of the discrepancy between the sexes occurs. For example, the sex-based disparity observed in ACL injury rates may be strongly influenced by differences in the frontal plane joint motions and moments.

The link between frontal plane knee loading and resultant increases in ACL strain is demonstrated by cadaveric, in vivo, and computer modeling experiments.[15,25,29,31] Physiologic dynamic valgus torques on the knee can significantly increase anterior tibial translation and load on the ACL severalfold.[15] A prospective combined biomechanical-epidemiologic study showed that knee abduction moments (valgus torques) and angles were significant predictors of future ACL injury risk.[21] During landing activities, females demonstrate more knee abduction (valgus) than males from a variety of heights and landing techniques, possibly placing the ACL in a vulnerable position.[§] Biomechanical research has focused on modifiable risk factors to reduce ACL injury risk, including the development of neuromuscular training protocols designed to modify landing techniques. However, despite advances in the understanding of injury mechanisms, the sex difference in ACL injury incidence is still present.[1]

While kinematic/kinetic evaluation of the knee has been a common method of evaluating ACL injury risk, not all studies show sex differences. Therefore, it is clinically relevant to determine why consistent sex differences do not occur throughout all landing movements. Differences in study design, population, and task may explain the lack of consistent results. Because of the greater number of ACL injuries in females, along with the identification of knee abduction as a risk factor for the injury, the purpose of this systematic review of the literature was to determine if females have significant differences in frontal plane knee motion and moments during landings compared with males. The results and potential methodological differences between studies were identified and presented. We

[§]References 7, 11, 12, 13, 16, 17, 19, 20, 21, 26, 27, 32, 35-37, 42.

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expect clinicians, coaches, and researchers to factor in, during their screening and risk identification procedures, landing movements that consistently display sex differences, especially with regard to sex differences in ACL injury.

METHODS

A systematic review of the literature involving sex differences while landing was performed. A search of MEDLINE, CINHAL, and SportDISCUS was conducted (1982–June 2010) with the following search keywords: "knee AND sport AND (abduction OR valgus OR frontal OR coronal) AND (sex OR gender)." The results were limited to studies that examined a landing maneuver (single or double leg), compared knee abduction (valgus) motion or moments between sexes, and used 3-dimensional motion analysis. We extracted the mean knee abduction (angle or moment) for male and female groups and whether the sex difference met statistical significance in the specific study. Joint moments were interpreted on the basis of external moment convention. Effect size (Cohen *d*)[10] and the confidence interval (95%) for the noncentrality parameter were estimated for each study that presented mean data.[38] Additional data that related to patient population, age, task, instrumentation, and variables were extracted from each article (Table 1). A standardized rating of each study was not included in this review.

RESULTS

A total of 27 studies met the study requirements and were included in this review (Table 1). The total number of subjects from the included studies was 1449 (853 female, 596 male), with sample sizes ranging from 12 to 315. All but 3 studies[9,24,28] used high-speed imaging systems with passive or active sensors. Sixty-three percent of the studies (15 of 24) that investigated angular motion found that females had significantly greater magnitudes of knee abduction compared with males. Only 8 articles analyzed in this review presented knee abduction moments during landings. Three studies (38%) found significantly greater external knee abduction moments in females compared with males. Of the 8 studies, only 2 reported internal moment conventions[26,27] and were transformed to external moments for interpretation throughout this review.

Not all the included studies provided the necessary data to calculate effect size. Rather, it was reported whether significant differences were observed and in which direction those differences were seen (ie, females greater than males). However, effect size was calculated for 24 instances of knee abduction angle (Figure 1). An effect size favoring knee abduction in females was calculated in 22 of the 24 instances (92%). Of these 22, large effect size (≥0.8) was calculated for 13 studies (59%), and moderate effect size (≥0.6) was calculated for 3 studies (14%). Of note, the only 2 instances in which an effect size favoring increased knee abduction in females was not calculated[9,40] also reported no significant difference between sexes.

Each of the included studies measured one or both of the previously mentioned variables, but the time frame (eg, initial contact, maximum during landing) in which data were evaluated varied (Figure 2). The landing phase of movements began at initial contact. In studies that evaluated the stop jump or drop vertical jump tasks, the first landing, prior to vertical jump, was used for evaluation (drop landings and forward hops involved only 1 landing). Regardless of landing task, the majority of studies (67%) evaluated the maximum value (peak) for abduction during the landing phase of the specified movement.[||] The second-most common event for evaluation (48%) occurred with each participant's initial contact with the ground, also described as *foot contact* or *heel contact*.[¶] Multiple studies identified a specific event during landing and reported the knee abduction variable at that corresponding event. These events included when the knee reached 40° of flexion,[36] peak knee flexion,[8,9,37,42] peak vertical ground reaction force,[8,9,33,39] and peak anterior shear force of the tibia,[7] and another evaluated the flight phase of a stop jump, just prior to landing.[6]

The majority (89%) of all included studies evaluated knee motion or moment at either initial contact or a maximum value. Of the 17 studies that reported sex differences when landing, 14 (83%) were among these groups. Among these 14 studies, 12 (86%) reported females landing with increased abduction compared with males.

DISCUSSION

Effects of Landing Movements

Of the studies included in this review, the landing phase of drop landings, stop jumps, forward hops, and drop vertical jumps were evaluated. Drop landings are often used to simulate decelerations experienced during athletic activities. Six studies investigated single-leg drops, compared with double-leg landings in 7 studies. Three of the single-leg investigations (50%) found that females demonstrated greater knee abduction than males[13,35,37] during drops from 13.5 cm, 40 cm, and 60 cm. Another study included single-leg drop landings from 60 cm and failed to identify significant difference in abduction moment but did show that males landed with a greater external adduction moment than females.[16] The remaining 2 studies, however, found no sex differences during single-leg landings.[28,33]

Studies involving double-leg landings have been more consistent in identifying sex differences in knee abduction. Of 7 studies involving 220 participants, 6 reported that females demonstrated greater abduction angles when landing. When performing a jump to a self-selected height, upon landing, females demonstrated greater abduction angles than males.[22] These findings were supported when performing drop landings from 60 cm,[27] 52 cm,[17] 50 cm,[26] and 40 cm.[35,36] Only 1 study reported no sex differences during a double-leg landing,[39] in which participants performed vertical jumps

[||]References 8, 11, 12, 13, 14, 16, 17, 19, 20, 22-24, 26-28, 32, 36, 40.

[¶]References 4, 9, 13, 17, 19, 20, 22, 27, 32, 33, 37, 39, 42.

to 50% of their maximum effort. Among participants included in this study, the mean vertical jump height ranged from 27.94 ± 4.97 cm for prepubescent girls to 55.79 ± 10.93 cm for adult males. Therefore, the mean drop height for participants was much lower than 40 cm, the lowest drop height among those reported for double-leg landings. Furthermore, while the previously mentioned study by Hughes et al[22] did not require participants to drop from a fixed height, it is reasonable to assume that collegiate volleyball players performing a block on a regulation net would demonstrate much greater jump heights than those used by Swartz[39] when no sex differences were observed.

The stop jump is another movement that requires a sudden deceleration but is followed immediately by rapid acceleration, usually in the form of a jump. The similarity with movements that are common in sports like basketball and volleyball make the stop jump a common maneuver in biomechanics research. It is a demanding maneuver that has been associated with noncontact ACL injuries.[5,34] No significant sex differences were found when the single-leg stop jump was performed.[4] However, when a double-leg stop jump was performed, females demonstrated greater knee abduction angles[42] and moments [7] during landing. An interesting study examined the flight phase prior to landing and found no sex differences in knee abduction angles and moments.[6]

As with the stop jump, 4 studies evaluated a total of 101 participants performing single-leg forward hops. One of the included studies showed females landing with greater knee abduction angles when following a 100-cm hop.[19] The remaining 3 studies failed to support these findings and reported no sex differences in abduction angle[23,24] or moment[8] upon landing. Only 1 study among these involved a predetermined distance for the hop.[19]

The drop vertical jump combines a drop landing with a maximum vertical jump. Attempting to rebound a shot in basketball or perform a spike or block in volleyball are just 2 examples of movements that might require an athlete to perform a vertical jump immediately following a landing. Eight studies assessed a total of 743 participants performing drop vertical jumps. Of the 8 studies, 5 showed that females landed with increased abduction angles.[11,12,14,20,32] Ford et al showed a difference in knee abduction angles at maximum between male and female basketball and soccer players.[14] This has been supported by 3 additional investigations; 2 involved the move from similar heights (30 cm).[11,20] McLean et al also confirmed these findings, in addition to increased abduction moment in females, when a drop vertical jump from 50 cm was performed.[32] Three studies reported no sex differences when a drop vertical jump was performed.[8,9,40] Two studies[8,9] involved recreational athletes, and another included male recreational athletes and collegiate female soccer players.[40] Participants performed the same movement to their maximum abilities.

Sex differences in knee abduction variables were most glaring during double-leg landings. Seventy-two percent of double-leg landings reported a significant difference between sexes, as opposed to just 45% among single-leg landings.

Effects of Landing Height and Jump Distance

In studies of drop landings, the height of the drop varied. Increased drop heights were associated with greater ground reaction forces upon landing.[41,43] Only 3 studies required landing from a drop of 30 cm or less. When participants landed on 1 leg from either 20 or 30 cm, no sex differences were found.[28,33] In a study with a height of only 13.5 cm with medial and lateral drops, females increased knee abduction angle during both landing conditions.[12] At 40 cm, females increased knee abduction angle during single- and double-leg landings.[35,36] Whether stepping off a box from a height of 50 cm or 52 cm, females increased knee abduction angle when landing with both legs.[17,27] At 60 cm, females increased both abduction angle and moment when landing with both legs[27] or a single leg.[37] Furthermore, Garrison et al found no sex difference in knee abduction moment, but males landed with increased knee adduction (varus) moment compared to females during single-leg landings.[16]

Swartz et al found no sex differences with a height set to 50% of each participant's maximum vertical jump.[39] To re-create actual demands in volleyball, Hughes et al used a rope at the height of a regulation volleyball net similar to blocking a shot by an opposing player and the subsequent 2-legged landings. Females demonstrated significantly greater knee abduction angle than males (–10.4° ± 7.7° vs –2.9° ± 7.9°).[22]

There were 8 drop vertical jump studies, 6 at 30 cm. Females demonstrated increased knee abduction angles in 4.[11,12,14,20] Sex differences were not found in 2 additional investigations.[8,9] At 50 cm, females landed with increased abduction angle and moment.[32] In the lone study that set the drop height at the participants maximum vertical heights, there were no sex differences.[40]

Unlike the studies with the various heights used in drop landing tests, studies involving the stop jump and forward hop tests generally did not include any standardized length of the jump. Rather, participants performed a self-selected approach toward the landing. In the one exception, participants performed a single-leg forward hop of 100 cm onto a force platform.[19] Females demonstrated greater knee abduction angles. The 3 forward hop studies without a predetermined jump distance all reported no sex differences with landing.[8,23,24]

Overall, studies suggest that when drop height/distance is standardized, sex differences in knee abduction are shown. Seven of 8 studies reported females landing with increased abduction angle or moment when performing a drop landing from a fixed height greater than 40 cm. By comparison, 2 of 3 studies reported no sex difference a drop landing was performed from 30 cm or lower.

(text continues on p. 381)

Table 1. Studies focused on sex differences in 3-dimensional (3D) calculated knee abduction.

Participants: Age, y	Tasks	Instrumentation	Variables	Results
Benjaminse (2008)[4]				
Recreational athletes Male (n = 15): 22.7 ± 1.6 Female (n = 15): 22.1 ± 1.7	Single-leg stop jump	3D passive motion 6 cameras	Knee abduction angle	No sex difference
Chappell (2007)[6]				
Recreational athletes Male (n = 17): 22.6 ± 2.2 Female (n = 19): 22.3 ± 2.2	Double-leg vertical stop jump	3D passive motion 8 cameras	Knee abduction angle Flight phase	No sex difference
Chappell (2002)[7]				
Recreational athletes Male (n = 10): 23.4 ± 1.1 Female (n = 10): 21.0 ± 1.7	Double-leg forward jump Double-leg vertical stop jump Double-leg backward jump	3D passive motion 4 cameras 2 force platforms	Knee abduction moment during landing	Females increased abduction
Chaudhari (2007)[8]				
Recreational athletes Male (n = 12): 20.3 ± 1.7 Female–no oral contraceptive (n = 12): 19.1 ± 1.0 Female–oral contraceptive (n = 13): 20.3 ± 1.0	Single-leg horizontal hop Double-leg box drop vertical Double-leg vertical jump	3D passive motion 2 cameras 1 force plate	Knee abduction moment	No sex difference
Cortes (2007)[9]				
University students (exercise 30 min/d at least 3 times/wk) Male (n = 25): 24.4 ± 2.3 Female (n =25): 23.3 ± 2.5	Double-leg box drop vertical	Electromagnetic sensors 2 force platforms	Knee abduction angle	No sex difference
Earl (2007)[11]				
Moderately active (exercise 30 min/d at least 3 times/wk) Male (n = 18): 23.5 ± 3.8 Female (n = 19): 22.2 ± 2.6	Double-leg box drop vertical Single-leg step down	3D passive motion 6 cameras	Knee abduction angle	Females increased abduction
Ford (2003)[12]				
High school basketball players Male (n = 34): 16.0 ± 1.2 Female (n = 47): 16.0 ± 1.4	Double-leg box drop vertical	3D passive motion 8 cameras 2 force platforms	Knee abduction angle	Females increased abduction

(continued)

Table 1. (continued)

Participants: Age, y	Tasks	Instrumentation	Variables	Results
Ford (2006)[13]				
College athletes (Division I) Male (n = 11) Female (n = 11)	Single-leg medial box drop Single-leg lateral box drop	3D passive motion 8 cameras 2 force platforms	Knee abduction angle	Females increased abduction at IC Females increased abduction peak
Ford (2010)[14]				
High school basketball and soccer Male–pubertal (n = 37) Male–postpubertal (n = 13) Female–pubertal (n = 145) Female–postpubertal (n = 120)	Double-leg box drop vertical	3D passive motion 8 cameras 2 force platforms	Knee abduction angle Knee abduction moment	Postpubertal females increased abduction compared to pubertal females Postpubertal females increased abduction compared to postpubertal males
Garrison (2005)[16]				
College soccer players Male (n = 8): 19.3 ± 1.5 Female (n = 8): 22.1 ± 2.4	Single-leg box drop	3D passive motion 10 cameras 1 force platform	Knee adduction moment Knee abduction moment	Females decreased adduction No sex difference
Gehring (2009)[17]				
Physically active Male (n = 13): 25.0 ± 2.4 Female (n = 13): 22.6 ± 1.5	Double-leg box drop landing	3D passive motion 6 cameras 1 force platform	Knee abduction angle	Females increased abduction
Hart (2008)[19]				
College soccer (Division I) Male (n = 8): 19.1 ± 1.4 Female (n = 8): 22.0 ± 2.1	Single-leg forward hop	3D passive motion 10 cameras 1 force platform	Knee abduction angle Knee abduction moment	Males decreased adduction angle No sex difference

(continued)

Table 1. (continued)

Participants: Age, y	Tasks	Instrumentation	Variables	Results
Hewett (2004)[20]				
Soccer and basketball players Male–prepubertal (n = 27): 12.0 ± 0.6 Male–pubertal (n = 24): 14.2 ± 1.4 Male–postpubertal (n = 30): 15.8 ± 1.7 Female–prepubertal (n = 14): 11.5 ± 0.7 Female–pubertal (n = 28): 12.6 ± 1.1 Female–postpubertal (n = 58): 15.5 ± 1.5	Double-leg box drop vertical	3D passive motion 8 cameras 2 force platforms	Knee abduction angle	Postpubertal females increased abduction compared with postpubertal males Postpubertal females increased abduction compared with prepubertal and pubertal females
Hughes (2008)[22]				
University volleyball players Male (n = 6): 21.6 ± 3.3 Female (n = 6): 21.2 ± 1.3	Double-leg volleyball block landing	3D passive motion 12 cameras 2 force platforms	Knee abduction angle	Females increased abduction
Jacobs (2005)[23]				
Recreational athletes Male (n = 8): 24.1 ± 2.2 Female (n = 10): 22.1 ± 2.3	Single-leg forward hop	3D passive motion 6 cameras	Knee abduction angle	No sex difference
Jacobs (2007)[24]				
Healthy adults Male (n = 15): 24.4 ± 3.0 Female (n = 15): 23.2 ± 2.9	Single-leg forward hop	Electromagnetic sensors	Knee abduction angle	No sex difference
Kernozek (2005)[27]				
Recreational athletes Male (n = 15): 24.5 ± 2.3 Female (n = 15): 23.6 ± 1.8	Double-leg drop landing	3D passive motion 6 cameras 1 force platform	Knee abduction angle Knee abduction moment	Females increased abduction Females decreased abduction moment
Kernozek (2008)[26]				
Recreational athletes Male (n = 16): 23.8 ± 0.4 Female (n = 14): 23.0 ± 0.9	Double-leg drop landing	3D passive motion 6 cameras 1 force platform	Knee abduction angle Knee abduction moment	Females increased abduction angle No sex difference in moment

(continued)

Table 1. (continued)

Participants: Age, y	Tasks	Instrumentation	Variables	Results
Kiriyama (2009)[28]				
Healthy high school students Male (n = 88): 17.1 ± 0.8 Female (n = 81): 16.9 ± 1.2	Single-leg box drop	3D optoelectronic tracking system 1 force platform	Knee abduction angle	No sex difference
McLean (2007)[32]				
College athletes (Division I) Male (n = 10): 20.7 ± 1.3 Female (n = 10): 20.8 ± 0.8	Double-leg box drop vertical	3D passive motion 6 cameras 2 force platforms	Knee abduction angle Knee abduction moment	Females increased abduction angle Females increased abduction moment
Nagano (2007)[33]				
University athletes Male (n = 18): 19.8 ± 4.6 Female (n = 19): 19.4 ± 0.9	Single-leg box drop	3D passive motion 7 cameras 1 force platform	Knee abduction angle	No sex difference
Pappas (2007)[35]				
Recreational athletes Male (n = 16): 28.8 ± 3.9 Female (n = 16): 28.2 ± 5.4	Double-leg box drop Single-leg box drop	3D passive motion 8 cameras 1 force platform	Knee abduction angle	Females increased abduction angle
Pappas (2007)[36]				
Recreational athletes Male (n = 16): 28.8 ± 3.9 Female (n = 16): 28.2 ± 5.4	Double-leg box drop	3D passive motion 8 cameras 1 force platform	Knee abduction angle	Females increased abduction angle
Russell (2006)[37]				
Healthy subjects Male (n = 16): 24 ± 5 Female (n = 16): 21 ± 6	Double-leg drop landing	3D passive motion 10 cameras 1 force platform	Knee abduction angle	Females increased abduction angle

(continued)

Table 1. (continued)

Participants: Age, y	Tasks	Instrumentation	Variables	Results
Swartz (2005)[39]				
Recreational athletes Male–adults (n = 14): 23.6 ± 3.2 Male–children (n = 15): 9.6 ± 1.0 Female–adults (n = 14): 24.2 ± 2.3 Female–children (n = 15): 9.2 ± 1.0	Double-leg landing (50% effort vertical jump)	3D passive motion 6 cameras 1 force platform	Knee abduction angle	No sex difference Children increased abduction angle compared with adults
Wallace (2008)[40]				
Female athletes (Division III), male athletes (recreational) Male (n = 11): 24.1 ± 3.4 Female (n = 11): 19.0 ± 0.9	Double-leg drop vertical	3D passive motion 6 cameras 1 force platform	Knee abduction angle	No sex difference
Yu (2005)[42]				
Youth recreational soccer players Male (n = 30): 5 per age group 11–16 Female (n = 30): 5 per age group 11–16	Double-leg vertical stop jump	3D passive motion 6 cameras 2 force platforms	Knee abduction angle	Females increased abduction angle Females increased abduction motion as they got older

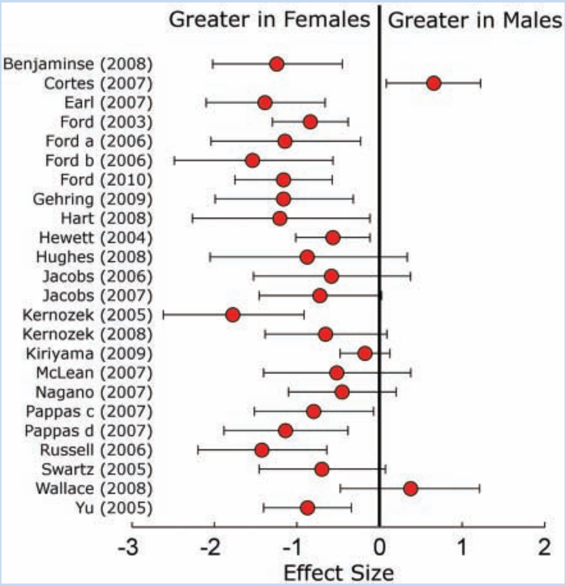

Figure 1. Calculated effect size of knee abduction angle differences between sexes.

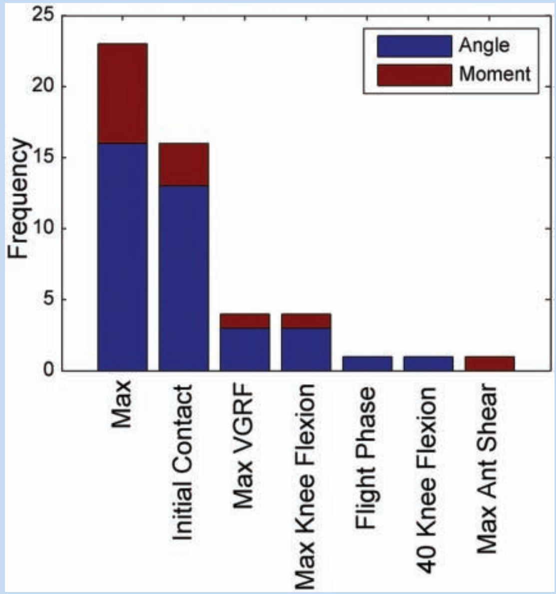

Figure 2. Frequency of abduction measurement events: distribution of studies that calculated abduction angle and moment during landings.

Effects of Participant Population

Although the research is limited, postpubertal females tend to increase knee abduction angles when landing compared with prepubertal and pubertal females.[20] Children demonstrate greater knee abduction than adults when landing, suggesting that physical development influences landing patterns, which in turn can affect injury risk.[39] In this review, the mean age ranged from 9.6 ± 1.0 years to 28.8 ± 3.9 years. Three studies involved 44 participants aged 11 years and younger; 3 studies involved 417 participants aged 12 to 17 years; and 22 studies involved 635 participants aged 18 years and older.

At least 4 studies suggested that age, or maturation, plays a role in frontal plane knee motion and, therefore, injury risk.[14,20,39,42] Swartz et al suggested that children (girls, 9.2 ± 1 years; boys, 9.6 ± 1.0 years) increased abduction angle when compared with adults (women, 24.2 ± 1.0 years; men, 23.6 ± 1.0 years).[39] Hewett et al reported that postpubertal females (15.5 ± 1.5 years) demonstrated greater abduction angles compared with pubertal (12.6 ± 1.1) and prepubertal (11.5 ± 0.7) females when performing drop landings.[20] Yu et al supported these findings demonstrating that females landed with greater abduction angles with increased age.[42] Under the age of 12 years, both males and females demonstrated knee abduction while landing. After age 12 years, females continued to increase knee abduction when landing, while males began to land in a varus knee position.[42] A longitudinal study by Ford et al found that knee abduction angle was significantly increased in pubertal females during rapid adolescent growth compared with males.[14] The activity level of participants and method for describing activity level varied among studies. Three studies gave no specific details regarding the participants' fitness levels or participation in exercise.[8,11,17]

The majority of studies involved recreational and/or competitive athletes, with a total of 790 participants included in these 2 groups. Eleven studies were included among the recreational athlete group, and the findings were inconsistent.[#] Findings among the competitive athlete group were more consistent at identifying sex differences (80%).[**] Among competitive athletes, females landed with increased abduction knee angle when performing drop landings[12,13,20,22] and single-leg hops[19] and increased abduction moment during drop vertical jumps.[32] Within this group, there were no significant sex differences during single- or double-leg landings.[16,33,40]

CONCLUSIONS

Females appear to land with greater knee abduction motion than males across a variety of movements common in high-risk sports measured in biomechanics studies. While the majority of the studies reported significant statistical differences between sexes, the effect sizes indicating an increase in abduction angle in females are even more convincing (Figure 1).

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