Journal of Athletic Training 2018;53(6):560–567
doi: 10.4085/1062-6050-426-16

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Passive Hip Range-of-Motion Values Across Sex and Sport

Jennifer A. Hogg, PhD, ATC*; Randy J. Schmitz, PhD, ATC†; Anh-Dung Nguyen, PhD, ATC‡; Sandra J. Shultz, PhD, ATC, FNATA, FACSM†

*University of Tennessee, Chattanooga; †University of North Carolina at Greensboro; ‡High Point University, NC

Context: Greater passive hip range of motion (ROM) has been associated with greater dynamic knee valgus and thus the potential for increased risk of anterior cruciate ligament injuries. Normative data for passive hip ROM by sex are lacking.

Objective: To establish and compare passive hip ROM values by sex and sport and to quantify side-to-side differences in internal-rotation ROM (ROM_{IR}), external-rotation ROM (ROM_{ER}), and total ROM (ROM_{TOT}).

Design: Cross-sectional study.

Setting: Station-based, preparticipation screening.

Patients or Other Participants: A total of 339 National Collegiate Athletic Association Division I athletes, consisting of 168 women (age = 19.2 ± 1.2 years, height = 169.0 ± 7.2 cm, mass = 65.3 ± 10.2 kg) and 171 men (age = 19.4 ± 1.3 years, height = 200.0 ± 8.6 cm, mass = 78.4 ± 12.0 kg) in 6 sports screened over 3 years: soccer (58 women, 67 men), tennis (20 women, 22 men), basketball (28 women, 22 men), softball or baseball (38 women, 31 men), cross-country (18 women, 19 men), and golf (6 women, 10 men).

Main Outcome Measure(s): Passive hip ROM was measured with the athlete lying prone with the hip abducted to 20° to 30° and knee flexed to 90°. The leg was passively internally and externally rotated until the point of sacral movement. Three measures were averaged for each direction and leg and used for analysis. We compared ROM_{IR}, ROM_{ER}, ROM_{TOT} ($ROM_{TOT} = ROM_{IR} + ROM_{ER}$), and relative ROM ($ROM_{REL} = ROM_{IR} - ROM_{ER}$) between sexes and among sports using separate 2 × 6 repeated-measures analyses of variance.

Results: Women had greater ROM_{IR} (38.1° ± 8.2° versus 28.6° ± 8.4°; $F_{1,327} = 91.74$, $P < .001$), ROM_{TOT} (72.1° ± 10.6° versus 64.4° ± 10.1°; $F_{1,327} = 33.47$, $P < .001$), and ROM_{REL} (1.5° ± 16.0° versus –7.6° ± 16.5°; $F_{1,327} = 37.05$, $P < .001$) than men but similar ROM_{ER} (34.0° ± 12.2° versus 35.8° ± 11.5°; $F_{1,327} = 1.65$, $P = .20$) to men. Cross-country athletes exhibited greater ROM_{IR} (37.0° ± 9.3° versus 30.9° ± 9.4° to 33.3° ± 9.5°; $P = .001$) and ROM_{REL} (5.9° ± 18.3° versus –9.6° ± 16.9° to –2.7° ± 17.3°; $P = .001$) and less ROM_{ER} (25.7° ± 7.5° versus 35.0° ± 13.0° to 40.2° ± 12.0°; $P < .001$) than basketball, soccer, softball or baseball, and tennis athletes. They also displayed less ROM_{TOT} (62.7° ± 8.1° versus 70.0° ± 9.1° to 72.9° ± 11.9°; $P < .001$) than basketball, softball or baseball, and tennis athletes.

Conclusions: Women had greater ROM_{IR} than men, resulting in greater ROM_{TOT} and ROM_{REL}. Researchers should examine the extent to which this greater bias toward ROM_{IR} may explain women's greater tendency for dynamic knee valgus. With the exception of cross-country, ROM values were similar across sports. The clinical implications of these aberrant cross-country values require further study.

Key Words: anterior cruciate ligment injury, screening, risk factor, normative data

Key Points

- Women had greater internal-rotation range of motion (ROM) than men regardless of sport, which resulted in women having greater total and relative ROM.
- The greater bias toward internal-rotation ROM may help explain the greater potential for females to display greater dynamic knee valgus.
- Cross-country athletes had greater internal-rotation ROM and less external-rotation ROM than athletes in every other sport studied except golf.
- The appreciable bilateral differences in some athletes suggested that measurements on 1 limb did not necessarily represent the other limb.

Of the approximately 200 000 anterior cruciate ligament (ACL) injuries sustained each year in the United States, 70% occur via noncontact mechanisms.[1,2] Dynamic knee valgus, comprising hip internal rotation (IR), hip adduction, knee abduction, and tibial external rotation (ER), is thought to contribute to noncontact ACL injury.[3] This is particularly true in females, who are more likely to display greater dynamic knee valgus during inciting injury mechanisms than their male counterparts based on retrospective videographic evidence.[3] However, less is known about factors precipitating dynamic knee valgus. Given that dynamic knee valgus is composed of hip-knee coupling in the frontal and transverse planes and movement occurs in a proximal-to-distal pattern,[4] a lack of control at the hip may be key to a lack of control at the knee.

From this perspective, available passive hip range of motion (ROM) has been presented as a potential contributor to dynamic knee valgus.[5,6] Whereas hip ROM can be influenced by active, or muscular, restraints, it is largely

Table 1. Currently Available Hip Range-of-Motion Data

Authors (Year)	Population	No.	Range of Motion (Mean ± SD), °	
			Internal Rotation	External Rotation
Nyland et al[13] (2004)	Female, active	18	43.3 ± 11	Not applicable
Sigward et al[8] (2008)	Female, soccer	39	42.7 ± 9.9	38.9 ± 8.6
Chiaia et al[14] (2009)	Female, soccer	26	32.5 ± 7.7	24.5 ± 6.3
Howard et al[6] (2011)	Male and female, active	45	29 ± 11	35 ± 7
Tainaka et al[15] (2014)	Male and female, active	123	50.2 ± 7.2[a]	56.3 ± 6.8[a]
Young et al[16] (2014)	Female, tennis	125	38 ± 41	23 ± 24
Fan et al[10] (2014)	Male, healthy	16	35.1 ± 4.7	41.9 ± 6.6
	Female, healthy	16	42.7 ± 10.3	41.1 ± 6.4
Moreno-Pérez et al[19] (2015)	Male, tennis	81	30.0 ± 9.6	50.6 ± 8.0
	Female, tennis	28	35.6 ± 8.2	49.3 ± 6.8

[a] Measured supine.

dictated by inert capsular constraints.[7] Therefore, greater passive ROM_{IR} may predispose an individual to move into more dynamic hip adduction and IR, leading to greater dynamic knee valgus. This may be especially apparent when greater ROM_{IR} occurs in conjunction with a lack of dynamic hip strength and control. In separate studies,[5,8] females with greater hip ROM_{IR} and less ROM_{ER} moved into more dynamic knee valgus throughout landing tasks. Combining these 2 variables (ROM_{IR} − ROM_{ER}) to represent an ROM_{IR} bias, Howard et al[6] showed that females who had greater ROM_{IR} relative to ROM_{ER}, along with weak hip abductors and external rotators, were more likely to move into greater knee abduction during a single-legged landing ($R^2 = 0.47$, $P < .001$). Whereas dynamic hip strength and control have long been considered a primary cause of dynamic knee valgus, these data suggest that excessive hip ROM may also play a role.

In addition to isolated ROM_{IR} and ROM_{ER} values, total hip ROM (ROM_{TOT}), which is the sum of ROM_{IR} and ROM_{ER}, may also contribute to the risk of ACL injury.[9] Individuals with greater ROM_{TOT} also display other characteristics thought to increase ACL injury risk. For instance, greater ROM_{TOT} has been associated with generalized joint laxity (r = 0.57),[10] a prospectively identified ACL injury risk factor in females.[11]

Although passive hip ROM during functional activity has been empirically linked to dynamic knee valgus during functional activity[6,12] and females have been reported to differ from males in passive hip ROM,[10] literature quantifying normative ranges of motion by sex is lacking. This gap can be particularly problematic considering that females may exhibit different injury mechanisms than males.[3] Previous reports of transverse-plane hip ROM values are presented in Table 1. Researchers who examined sex differences in ROM_{IR} and ROM_{ER} have suggested that females possess more ROM_{IR} than ROM_{ER} and more ROM_{IR} than males in a healthy population[10] and elite tennis players.[16] However, as a result of the limited data on athletic populations, these sex comparisons may not be generalizable to individuals participating across a variety of sports. Furthermore, available ROM data by sport are limited to soccer and tennis athletes.[8,15] Because of different lower extremity demands among sports, passive hip ROM may differ by sport. More importantly, given the higher rates of ACL injury in sports such as basketball and soccer[2,17] and the evidence of a greater sex disparity in ACL injuries in these sports, understanding the sex- and sport-specific patterns of hip ROM may help explain these disparities. Therefore, the primary purpose of our study was to establish normative values for absolute and relative passive hip ROM (ROM_{IR}, ROM_{ER}, ROM_{TOT}, and relative ROM [ROM_{REL}]) for each sex and various sports and to compare these values between sexes and among sports. We hypothesized that women would exhibit greater ROM_{IR}, and thus greater ROM_{REL} and ROM_{TOT}, than men. With the higher rates of ACL injury in basketball and soccer players, we also hypothesized that women participating in these sports would have greater ROM_{IR},[2,17] which would result in higher ROM_{REL} values. Our secondary purpose was to quantify the side-to-side differences for ROM_{IR}, ROM_{ER}, and ROM_{TOT} to help clinicians determine whether 1 limb can represent both limbs during screening protocols and for return-to-play criteria.

METHODS

We recruited 339 National Collegiate Athletic Association Division I varsity athletes from 1 institution over 3 years. Participants were 168 women (age = 19.2 ± 1.2 years, height = 169.0 ± 7.2 cm, mass = 65.3 ± 10.2 kg) and 171 men (age = 19.4 ± 1.3 years, height = 200.0 ± 8.6 cm, mass = 78.4 ± 12.0 kg). Female and male baseball, basketball, cross-country, golf, soccer, softball, and tennis athletes were included. The numbers of participants by sex, sport, and examiner are presented in Table 2. Athletes not cleared for full participation at the time of their preparticipation examinations were excluded from the study. All recruits provided written informed consent, and the study was approved by the Institutional Review Board at the University of North Carolina at Greensboro.

Procedures

All data were collected using established measurement techniques[18] in conjunction with the athletes' preparticipation examinations. Only data from the earliest year of data collection were included. We obtained all passive hip ROM measurements bilaterally using a 0° to 360° bubble inclinometer (Saunders Manufacturing, Readfield, ME) with 2° increments that was positioned on the anterior side of the tibia along the longitudinal tibial axis. Each participant was positioned prone with the hip in 0° of extension and 20° to 30° of abduction (Figure 1); sagittal-plane neutral hip positioning minimized muscular involvement. The knee was flexed to 90°. The leg was passively

Table 2. Number of Participants by Examiner, Sex, and Sport

Participant	Examiner 1	Examiner 2	Total
Women, No.	75	93	168
Soccer	30	28	58
Tennis	11	9	20
Basketball	15	13	28
Softball/baseball	19	19	38
Cross-country	0	18	18
Golf	0	6	6
Men, No.	51	120	171
Soccer	30	37	67
Tennis	12	10	22
Basketball	9	13	22
Softball/baseball	0	31	31
Cross-country	0	19	19
Golf	0	10	10
Total	126	213	339

rotated internally and externally until initial sacral tilt as determined by the examiner's palpation. At this point, the transverse angle formed by true vertical and the tibial diaphysis were considered ROM_{ER} and ROM_{IR}, respectively. We summed ROM_{ER} and ROM_{IR} to calculate ROM_{TOT}. To calculate ROM_{REL}, we subtracted ROM_{ER} from ROM_{IR}. This relative ROM_{IR} variable retained the original degree unit and has been used in the literature to represent the amount of bias toward ROM_{IR}.[6] Three trials were obtained bilaterally for ROM_{IR} and ROM_{ER} and averaged for analysis. Two examiners (J.A.H., A.N.) with good to excellent between-days reliability (intraclass correlation coefficient [2,3; standard error of measurement]) took all measurements (examiner 1: $ROM_{IR} = 0.97$ [1.6°], $ROM_{ER} = 0.85$ [3.3°]; examiner 2: $ROM_{IR} = 0.87$ [2.5°], $ROM_{ER} = 0.83$ [1.8°]). A single examiner (J.A.H. or A.N.) took all measurements within each year of testing. The numbers of men and women measured by each examiner were relatively balanced except for softball and baseball, as baseball was only measured for 1 year by examiner 2. The distribution of sports between examiners was also relatively balanced except for cross-country and golf, which were measured only by examiner 2 (Table 2).

Statistics

Histograms were constructed for each variable of interest to inspect normality of distribution. Descriptive statistics (means and standard deviations) were also computed for each variable. Paired *t* tests confirmed no appreciable differences in bilateral ROM_{IR} or ROM_{ER}. Therefore, four 2×6 (sex by sport) between-subjects analyses of variance were performed with average ROM_{IR}, ROM_{ER}, ROM_{TOT}, and ROM_{REL} as dependent variables. Except for softball and baseball, all sports were represented by both male and female athletes. Given the similar lower extremity demands of softball and baseball, these sports were considered as 1 sport for comparisons between sexes and with the other sports. To adjust for all 4 comparisons using a Bonferroni correction, we set the a priori α level for the omnibus analysis-of-variance models at .0125. Tukey post hoc analyses ($\alpha \leq .05$) were applied to main effects as appropriate. We computed left-right limits of agreement and Bland-Altman plots to determine the suitability of using measures on 1 limb to represent both limbs. We used SPSS for all primary analyses (version 21; IBM Corp, Armonk, NY). Limits of agreement and Bland-Altman plots were computed using R (2015; R Foundation for Statistical Computing, Vienna, Austria).

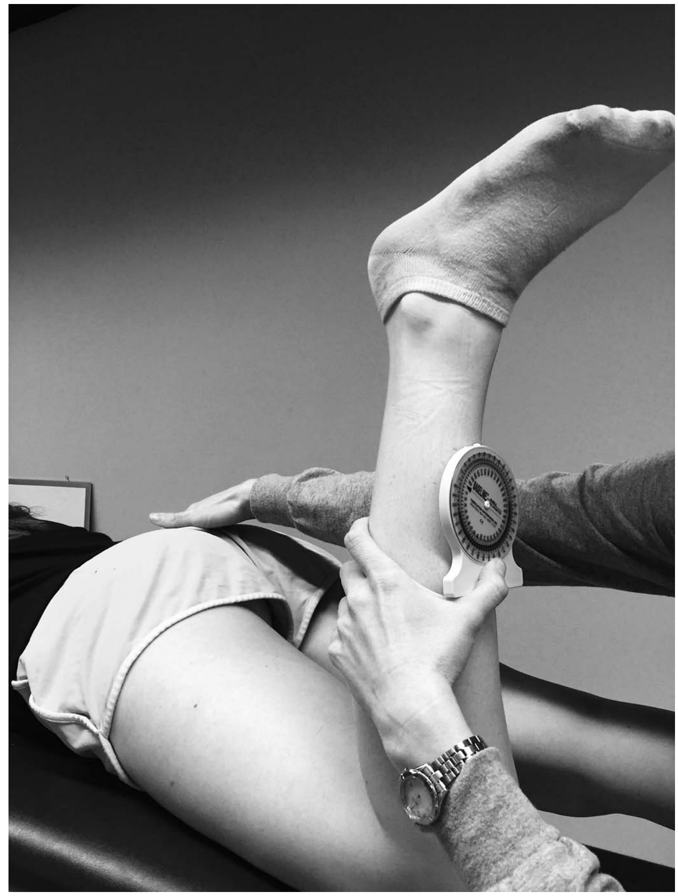

Figure 1. Positioning for all range-of-motion measures. The participant lay prone with the hip slightly abducted and the knee flexed. The examiner passively rotated the tibia while monitoring sacral tilt.

RESULTS

Means and standard deviations for each variable, stratified by sex and sport, are presented in Table 3. Women exhibited greater ROM_{IR} (38.1° ± 8.2° versus 28.6° ± 8.4°; $F_{1,327} = 91.74$, $P < .001$), ROM_{TOT} (72.1° ± 10.6° versus 64.4° ± 10.1°; $F_{1,327} = 33.47$, $P < .001$), and ROM_{REL} (1.5° ± 16.0° versus –7.6° ± 16.5°; $F_{1,327} = 37.05$, $P < .001$) than men. We observed similar ROM_{ER} between women (34.0° ± 12.2°) and men (35.8° ± 11.5°; $F_{1,327} = 1.65$, $P = .20$). Main effects by sport were present for ROM_{IR} ($F_{5,327} = 4.51$, $P = .001$), ROM_{ER} ($F_{5,327} = 9.47$, $P < .001$), ROM_{TOT} ($F_{5,327} = 6.10$, $P < .001$), and ROM_{REL} ($F_{5,327} = 11.51$, $P = .001$). Follow-up post hoc analyses revealed that cross-country athletes exhibited greater ROM_{IR} (37.0° ± 9.3° versus 30.9° ± 9.4° to 33.3° ± 9.5°), lesser ROM_{ER} (25.7° ± 7.5° versus 35.0° ± 13.0° to 40.2° ± 12.0°), and greater ROM_{REL} (5.9° ± 18.3° versus –9.6° ± 16.9° to –2.7° ± 17.3°) than basketball, soccer, softball and baseball, and tennis athletes and less ROM_{TOT} (62.7° ± 8.1° versus 70.0° ± 9.1° to 72.9° ± 11.9°) than basketball, softball and baseball, and tennis athletes. We

Table 3. Hip Range of Motion by Sport and Sex

	Range of Motion (Mean ± SD), °			
	Internal Rotation	External Rotation	Total	Relative Internal Rotation
Basketball				
Women	37.9 ± 7.7	38.4 ± 11.2	76.2 ± 11.1	−0.5 ± 14.0
Men	28.7 ± 9.5	39.9 ± 12.7	68.6 ± 11.8	−11.1 ± 18.5
Total	33.3 ± 9.5	39.1 ± 11.8	72.9 ± 11.9	−5.2 ± 16.8
Cross-country				
Women	41.4 ± 9.2	23.3 ± 7.1	64.7 ± 8.7	14.2 ± 15.9
Men	32.6 ± 7.2	28.5 ± 6.2	60.7 ± 7.3	−1.9 ± 17.3
Total	37.0 ± 9.3[a]	25.7 ± 7.5[a]	62.7 ± 8.1[b]	5.9 ± 18.3[a]
Golf				
Women	41.7 ± 4.3	31.5 ± 7.6	73.2 ± 7.5	10.2 ± 8.4
Men	27.9 ± 7.7	34.3 ± 6.0	62.2 ± 5.6	−7.5 ± 13.4
Total	34.8 ± 9.5	32.9 ± 6.6	66.3 ± 8.2	−0.9 ± 14.5
Soccer				
Women	35.8 ± 7.5	34.9 ± 13.2	70.7 ± 10.9	1.4 ± 16.4
Men	26.2 ± 8.4	35.2 ± 12.9	61.4 ± 11.0	−6.3 ± 17.4
Total	31.0 ± 9.3	35.0 ± 13.0	65.7 ± 11.9[c]	−2.7 ± 17.3
Softball or baseball				
Women	36.2 ± 8.4	38.7 ± 10.4	74.9 ± 8.2	−2.5 ± 16.0
Men	29.4 ± 6.9	34.5 ± 6.4	63.9 ± 6.0	−5.1 ± 10.8
Total	32.8 ± 8.5	36.6 ± 9.1	70.0 ± 9.1	−3.6 ± 13.9
Tennis				
Women	35.3 ± 7.9	37.4 ± 11.8	72.7 ± 11.5	−2.1 ± 14.1
Men	26.6 ± 8.9	43.0 ± 11.6	69.6 ± 10.3	−16.5 ± 16.6
Total	30.9 ± 9.4	40.2 ± 12.0	71.1 ± 10.9	−9.6 ± 16.9
Total				
Women	38.1 ± 8.2[d]	34.0 ± 12.2	72.1 ± 10.6[d]	1.5 ± 16.0[d]
Men	28.6 ± 8.4[d]	35.8 ± 11.5	64.4 ± 10.1[d]	−7.6 ± 16.5[d]

[a] Different from all groups except golf ($P < .01$).
[b] Different from softball/baseball, basketball, and tennis ($P < .01$).
[c] Different from basketball ($P < .01$).
[d] Different from all other groups ($P < .01$).

observed no interactions for any variable by sex and sport (P range = .32–.82).

When we examined bilateral asymmetries, mean side-to-side differences (left-right) for ROM_{IR}, ROM_{ER}, ROM_{TOT}, and ROM_{REL} were –0.13°, –0.99°, –1.13°, and 0.86°, respectively, indicating minimal systematic bias. We observed that 68% and 95% of values were within 6.8° and 13.4° of the mean for ROM_{IR}, 7.4° and 14.5° for ROM_{ER}, 6.2° and 12.1° for ROM_{TOT}, and 12.8° and 25.0° for ROM_{REL}. Bland-Altman plots are presented in Figures 2 through 5.

DISCUSSION

Our primary findings that women exhibited greater ROM_{IR} than and similar ROM_{ER} to men, resulting in greater ROM_{TOT} and ROM_{REL}, supported our hypothesis. Given that ROM_{ER} was similar between sexes, the observed sex differences in ROM_{TOT} and ROM_{REL} can be attributed to the greater ROM_{IR} in women. Secondarily, cross-country athletes, regardless of sex, displayed greater ROM_{IR} and lesser ROM_{ER}, resulting in increased ROM_{REL}.

For women, the ROM_{IR} and ROM_{ER} values were 38.1° ± 8.2° and 34.0° ± 12.2°, respectively, which agreed with previous work using similar methods (Table 1). We located only 1 published study[19] in which the authors used a prone measurement technique in an all-male cohort and reported values of 30.0° ± 9.6° for ROM_{IR} and 50.6° ± 8.0° for ROM_{ER}, which were considerably higher than the values of 28.6° ± 8.4° and 35.8° ± 11.5°, respectively, in our study. Differences in measurement collection may explain this; in the previous study,[19] the ROM endpoint was designated as the examiner's perception of firm resistance, whereas in our study, the endpoint was signified by initial sacral tilt, which would likely occur before the perception of firm resistance.

Differences Between Sexes

Women displayed greater ROM_{IR} than men (38.1° ± 8.2° versus 28.6° ± 8.4°). This could have clinical implications with respect to observed sex disparities in ACL injuries and patellofemoral pain syndrome.[20,21] Evidence[6] has suggested that an increase in ROM_{IR} may be associated with a higher prevalence of dynamic knee valgus, especially in females. During activity, an athlete with more available ROM_{IR} might be predisposed to exhibit greater dynamic IR, which is a component of dynamic knee valgus that is thought to increase the risk of ACL injury.[22,23] Researchers[24,25] have also postulated that excessive dynamic IR of the hip may be associated with chronic, repetitive loading of the patellofemoral joint, leading to patellofemoral pain, a condition more commonly observed in females.

Whereas sex differences in ROM_{TOT} were affected by ROM_{IR}, we are hesitant to discount the potential importance of ROM_{TOT}. Increased ROM_{TOT}, as a measure of ligamentous laxity, may have implications for lower extremity injury risk. Total ROM has been associated with generalized joint laxity,[10] a prospectively identified ACL injury risk factor in females,[11] and may place greater demands on the hip musculature to stabilize the joint during dynamic activity. Investigators should determine the contributions of ROM_{TOT} to dynamic knee control and potential injury risk, whether these contributions are separate from those of ROM_{IR}, and whether differences in ROM_{TOT} may partially explain observed sex disparities in lower extremity injuries.

To address potential between-sexes effects due to examiner differences, we conducted secondary analyses within the cohort measured by examiner 2. The results were consistent, as females displayed greater ROM_{IR} (39.3° ± 7.3° versus 29.8° ± 7.5°) and ROM_{TOT} (65.7° ± 8.5° versus 59.9° ± 8.7°) than males. Therefore, we contend that the observed sex differences are true differences and not a result of interexaminer differences.

Differences Among Sports

Despite our hypothesis that passive hip ROM would differ among sports, the divergent values displayed in cross-country, a sport not known for ACL injuries, are surprising. Cross-country athletes had greater ROM_{IR} (37.0° ± 9.3° versus 30.9° ± 9.4° to 33.3° ± 9.5°) and less ROM_{ER} (25.7° ± 7.5° versus 35.0° ± 13.0° to 40.2° ± 12.0°) than athletes in the other sports, resulting in less ROM_{TOT} (62.7° ± 8.1° versus 70.0° ± 9.1° to 72.9° ± 11.9°) and greater ROM_{REL} (5.9° ± 18.3° versus –9.6° ± 16.9° to –2.7° ± 17.3°). Given that the data on all cross-country athletes were obtained by the same examiner (Table 2), secondary analyses were conducted within those

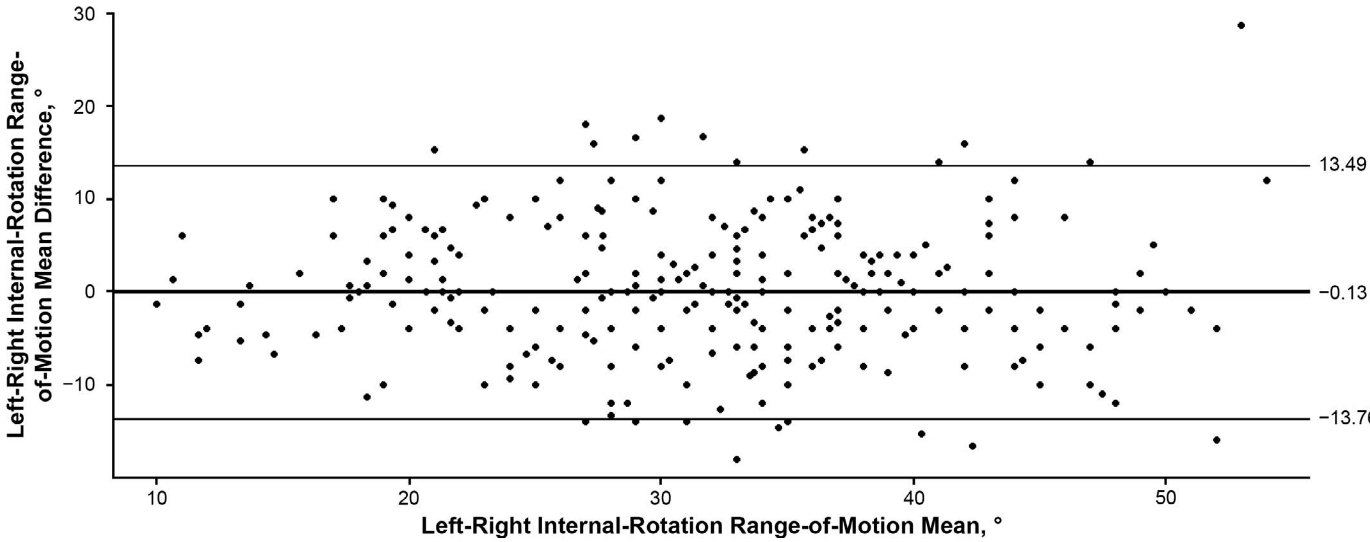

Figure 2. Bland-Altman plot comparing the left-right internal-rotation range of motion, representing the left-right mean difference and 95% confidence interval.

athletes measured by examiner 2 to confirm that differences were not due to the examiner. Similar trends were revealed; cross-country athletes had greater ROM_{IR} than athletes in all other sports (37.0° ± 9.3° versus 32.5° ± 7.1° to 36.8° ± 8.2°) and less ROM_{ER} than athletes in all other sports except soccer (25.7° ± 7.1° versus 30.3° ± 6.3° to 32.9° ± 6.6°, soccer = 24.3° ± 6.0°). Within examiners, these differences resulted in cross-country athletes having lower ROM_{TOT} than athletes in all other sports except soccer (62.7° ± 8.1° versus 63.6° ± 7.8° to 67.1° ± 10.2°, soccer = 58.2° ± 9.5°) and greater ROM_{REL} than athletes in all other sports except soccer and basketball (5.9° ± 18.3° versus –0.9° ± 14.9° to 0.9° ± 11.1°, soccer = 9.0° ± 12.1°, basketball = 6.6° ± 10.6°). Whereas having multiple testers is frequently a reality in multiseason screening, it is not ideal and often introduces "noise" into the data. Despite this, our secondary analyses suggested that the observed differences are true and cannot be fully attributed to discrepancies between examiners.

Given the lack of cutting and lateral movement in cross-country, excessive dynamic hip IR may not lead to an increased ACL injury risk in this population, but it may help explain the increased prevalence of patellofemoral pain syndrome in runners. Ho et al[26] postulated that excessive dynamic hip IR repetitively loads the patellofemoral joint, leading to an acute change in patellar composition. Excessive dynamic hip IR during running has also been repeatedly suggested[25,27,28] to contribute to the higher incidence of patellofemoral pain observed in female runners.

Side-to-Side Limits of Agreement

Calculating side-to-side differences via limits of agreement can aid clinicians in determining if 1 limb can be used as a suitable representation of both limbs. If passive hip ROM is equal bilaterally, the healthy limb could then serve as a baseline for the injured limb. In our sample, the average mean difference was close to zero, indicating little

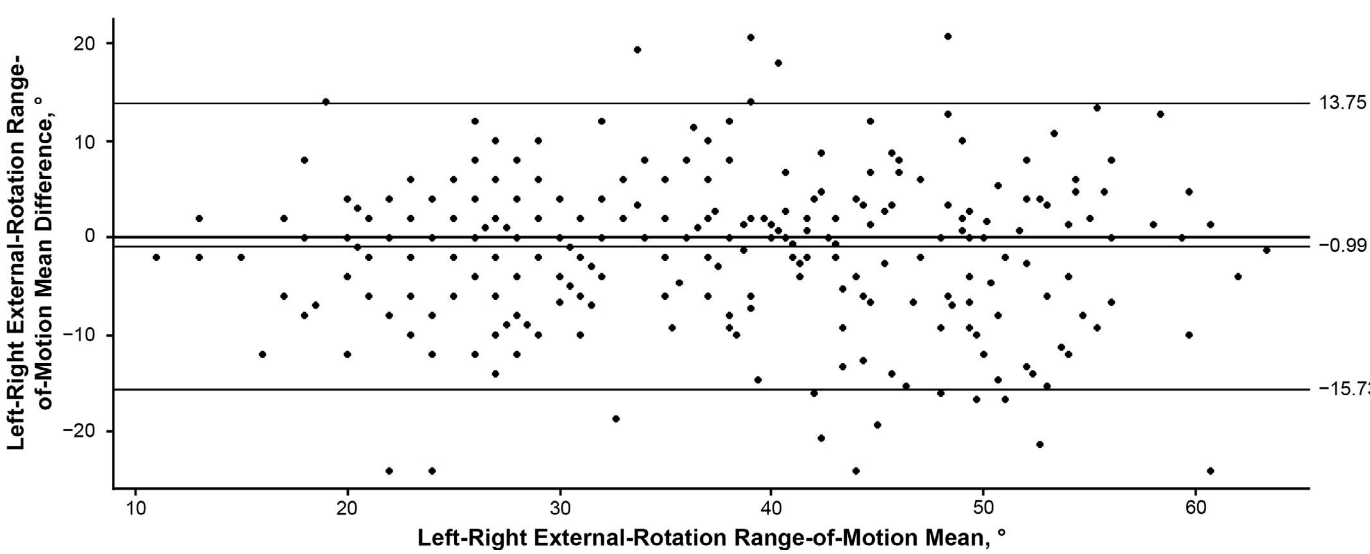

Figure 3. Bland-Altman plot comparing the left-right external-rotation range of motion, representing the left-right mean difference and 95% confidence interval.

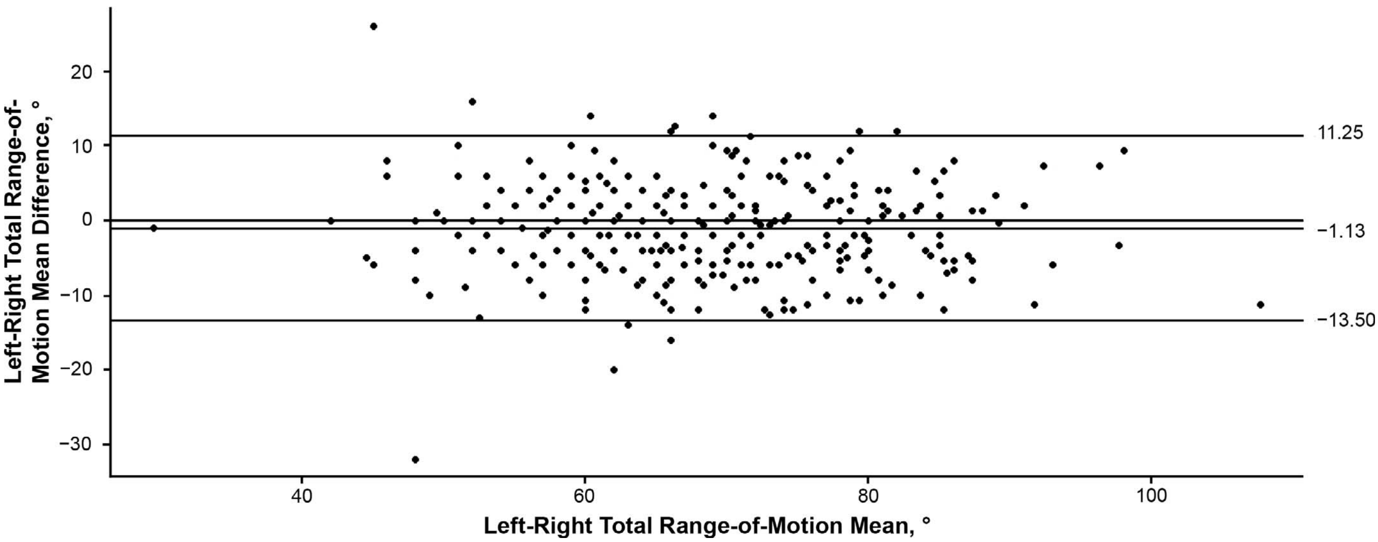

Figure 4. Bland-Altman plot comparing the left-right total range of motion, representing the left-right mean difference and 95% confidence interval.

to no systematic bias present between left and right passive hip ROM. However, the observed magnitudes of left-right differences varied considerably. For ROM_{IR}, ROM_{ER}, and ROM_{TOT}, 32% of the sample had left-right ROM differences that exceeded 6.8°, 7.4°, and 6.2°, respectively, and 5% of the sample had left-right mean differences greater than 13.4°, 14.5°, and 12.1°. The observed left-right differences in ROM_{IR} and ROM_{ER} were substantially greater than what we would expect simply because of test-retest measurement error (Figure 6), which suggests that, in some individuals, ROM_{IR} and ROM_{ER} are appreciably different bilaterally, and therefore measurement of 1 limb may not adequately represent the other limb for screening purposes. In contrast to ROM_{IR} and ROM_{ER}, left-right differences in ROM_{TOT} were similar to the expected test-retest measurement error, indicating that measurement of the entire envelope of passive hip ROM on 1 side may appropriately represent the other side. Clinically, this may imply that some athletes exhibit a unilateral bias toward either ROM_{IR} or ROM_{ER} while maintaining the same amount of ROM_{TOT}, which was confirmed by the limits of agreement computed from ROM_{REL} (Figure 5). One-third of the sample displayed side-to-side ROM_{REL} differences exceeding 12.8°, and 5% exceeded bilateral differences of 25.0°, indicating that, in some athletes, the configuration of the passive hip ROM envelope may be markedly different bilaterally. This could result in a tendency for 1 limb to move into greater or lesser amounts of hip IR during movement. Howard et al[6] used ROM_{REL} as an estimate of femoral anteversion. Given that left-right differences in femoral anteversion have only been shown to exceed 6.9° in some individuals,[29] more research is needed to determine the amount of ROM_{REL} that can be explained by femoral anteversion and how much can be attributed to factors such as sport-specific adaptations.

Clinically, in some individuals, 1 limb may not be representative of the other with respect to ROM_{IR} and ROM_{ER}. This may be especially important considering that

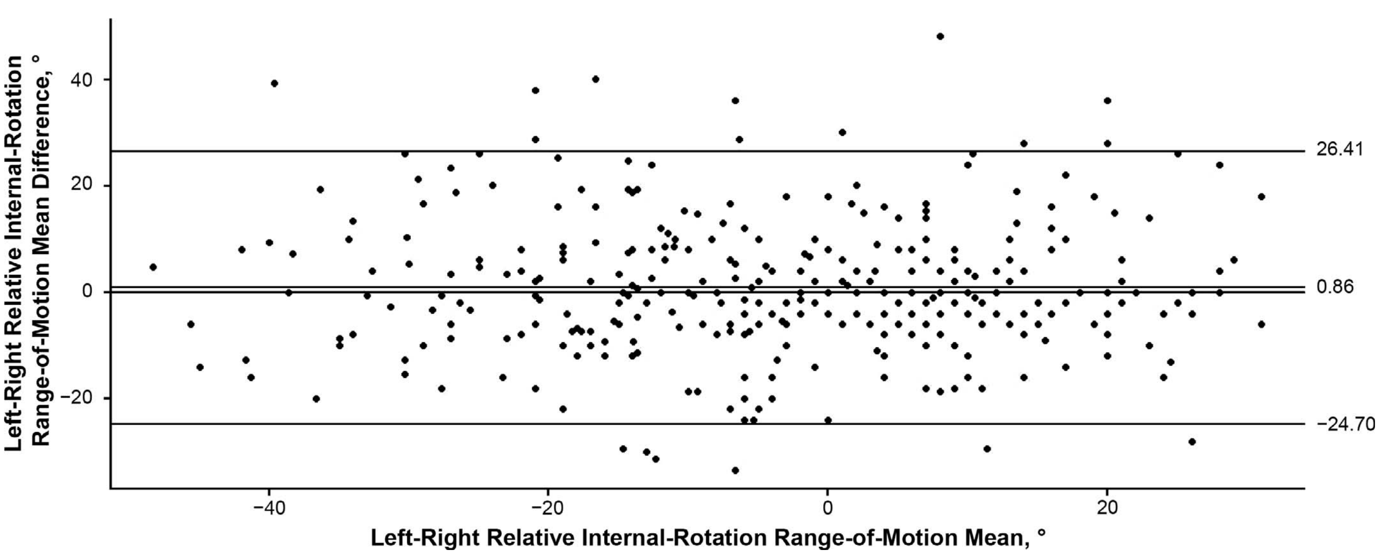

Figure 5. Bland-Altman plot comparing the left-right relative internal-external rotation range of motion, representing left-right mean difference and 95% confidence interval.

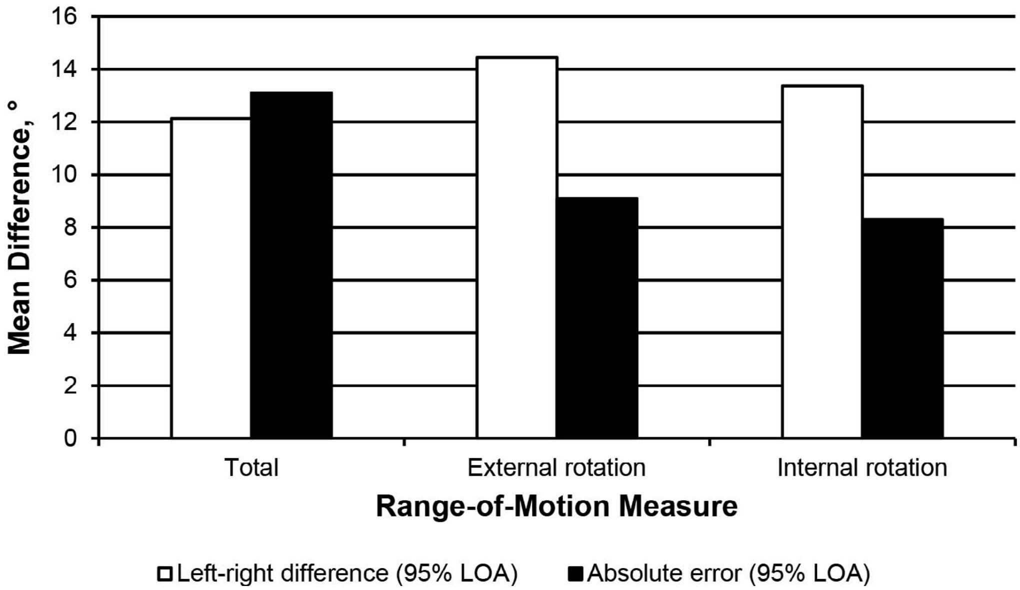

Figure 6. Comparison of absolute measurement error with the observed left-right differences. Abbreviation: LOA, limit of agreement.

potential left-right differences for ROM_{IR} and ROM_{ER} account for a sizeable portion of the total available ROM. For example, two-thirds of our sample was within 6.8° of ROM_{IR} bilaterally, and 95% was within 13.4°. For females, this could represent 19% to 37% of overall ROM, which may have important clinical implications. A bilateral difference of 5° of ROM_{IR} may lead to more substantial consequences in an athlete with less ROM_{TOT} than in an athlete with greater ROM_{TOT}.

Our study had limitations. Whereas each examiner had established good to excellent intrarater reliability before data collection, we acknowledge that having 1 examiner obtain all measurements would have been preferable. Because the data were collected in nonconsecutive years, we were unable to establish intertester reliability. However, both examiners were experienced clinicians and were similarly trained in obtaining these measures using established laboratory measurement techniques. In addition, all data for any given year were collected by the same examiner, making it possible to compare means between sexes and among sports within each year and examiner to ensure data fidelity and that our primary findings held for both examiners. Another limitation was the accuracy of the bubble inclinometer used for collection, as we could record values only in 2° increments. However, the same instrument was used when assessing measurement error and our planned comparisons, and the observed differences well exceeded the measurement error. In addition, whereas these data were obtained from athletes medically cleared for full participation, athletes who had recently been injured or who had a history of lower extremity surgery were not excluded. Although we acknowledge that passive hip ROM may be affected by previous lower extremity surgery or injury, we maintain that our sample was representative of one typically found in athletics. Lastly, including normative hip-strength data would have rendered a more complete picture of how altered hip ROM couples with strength to influence lower extremity movement patterns. We did not collect these data, but they present an avenue for future research.

CONCLUSIONS

Women exhibited greater ROM_{IR} than men regardless of sport, which resulted in women having greater ROM_{TOT} and higher ROM_{REL}. This may, in part, explain the increased potential for females to display greater dynamic knee valgus. Researchers should investigate the potential neuromuscular and biomechanical implications of these sex differences to determine the contributions of different ROM values to ACL injury risk and the extent to which passive hip ROM is modifiable or can be countered by dynamic hip strength and control and potentially serve as a target for injury-prevention strategies. Moreover, cross-country athletes displayed greater ROM_{IR} and less ROM_{ER} than athletes in all other sports except golf. The causes of these divergent values and potential clinical implications warrant further investigation. Lastly, some athletes showed appreciable bilateral differences, suggesting that measurements on 1 limb do not necessarily represent the other limb. Reasons for these discrepancies, as well as the implications this may have on potential injury risk, require further study.

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Address correspondence to Jennifer A. Hogg, PhD, ATC, University of Tennessee, 518 Oak Street, Chattanooga, TN 37411. Address e-mail to jennifer-hogg@utc.edu.