**Sex Difference in Hip Adduction during Running: Influence of Hip Abductor Strength,
Activation, and Pelvis & Femur Morphology**

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ABSTRACT

Purpose: To examine the influence of hip abductor strength, neuromuscular activation, and pelvis & femur morphology in contributing to sex differences in hip adduction during running.

Methods: Fifteen female and 14 male runners underwent strength testing, instrumented overground running (e.g., kinematics and muscle activation), and computed tomography scanning of pelvis and femur. Morphologic measurements included bilateral hip width to femur length ratio, acetabulum abduction, acetabulum anteversion, femoral anteversion, and femoral neck-shaft angles. Sex differences for all variables were examined using independent t-tests. Linear regression was used to assess the ability of each independent variable of interest to predict peak hip adduction during the late swing and stance phase of running.

Results: Compared to males, females exhibited significantly greater peak hip adduction during both late swing ($8.5 \pm 2.6^\circ$ vs $6.2 \pm 2.8^\circ$, $p = 0.04$) and stance phases of running ($13.4 \pm 4.2^\circ$ vs $10.0 \pm 3.2^\circ$, $p = 0.02$). In addition, females exhibited significantly lower hip abductor strength (1.8 ± 0.3 vs 2.0 ± 0.3 Nm/kg, $p=0.04$), greater femoral neck-shaft angles ($134.1 \pm 5.0^\circ$ vs $129.9 \pm 4.1^\circ$, $p=0.01$), and greater hip width to femur length ratios than males (0.44 ± 0.02 vs 0.42 ± 0.03 , $p=0.03$). Femoral anteversion was the only significant predictor of peak hip adduction during late swing ($r=0.36$, $p=0.05$) and stance ($r=0.41$, $p=0.03$).

Conclusion: Our findings highlight the contribution of femur morphology as opposed to hip abductor strength and activation in contributing to hip adduction during running.

Keywords: hip kinematics; gluteus medius; strength; EMG

INTRODUCTION

Compared to males, females have been reported to exhibit higher degrees of hip adduction during running (1-5). Greater hip adduction has been shown to be contributory to several running injuries (6-10) and may explain the higher incidence of certain running injuries in women compared to men (i.e., patellofemoral pain) (6,11). For this reason, there has been interest in understanding the underlying causes of excessive hip adduction in female runners.

Sex differences in hip adduction have long been postulated to be the result of diminished strength and/or activation of the hip abductors. While some studies have reported lower hip abductor torque production in females compared to males (12-14), others have not (15-17). In addition, previous investigations have found that hip abductor strength is either not correlated with hip adduction (18-21), or weakly associated in females only (17). With respect to neuromuscular recruitment, previous studies have reported similar levels of gluteus medius activation between males and females during various activities, even though females in these studies demonstrated significantly greater hip adduction than their male counterparts (18,19,21). Furthermore, gluteus medius activation has not been reported to be predictive of hip adduction during running (22).

Another potential contributor to sex differences in hip adduction during running is pelvis and femur skeletal morphology. For example, a greater bilateral hip width relative to femur length ratio would theoretically require larger degrees of hip adduction to position the foot under the center of mass at ground contact. In addition, smaller degrees of acetabulum abduction and/or femoral neck-shaft angles could bias the hip into greater hip adduction. Furthermore, femoral anteversion and acetabulum anteversion may affect frontal plane hip kinematics. The potential influence of femoral anteversion and acetabulum anteversion on hip adduction is highlighted by a study that reported individuals who exhibited greater femoral anteversion also exhibited greater

degrees of frontal plane knee motion during a single-leg landing task (23). Taken together, the premise that bony structure (as opposed to strength) may play a role in influencing hip kinematics is supported by the findings from a previous study that hip adduction during the late swing phase of running was highly predictive of peak hip adduction during stance (24).

To date, few studies have examined the potential influence of pelvis and/or femur morphology on hip adduction during running. Studies examining the bilateral hip width to limb length ratio (22) and bilateral greater trochanteric distance to femur length ratio (25) have reported non-significant or very low associations with hip adduction during running, respectively. Similarly, Baggaley et al. (26) reported that femoral neck-shaft angle was not associated with the magnitude of hip adduction in females during running. However, a limitation of previous work in this area is that measures of pelvis and femur morphology were either estimated from external markers (22) or were obtained from 2D radiographs (26). Such measurements are prone to error (27,28) and may not accurately represent true structural morphology.

Given that joint kinematics are likely influenced by the complex interaction of muscular actions and skeletal structure, the purpose of the current study was to examine the role of hip abductor strength, neuromuscular activation, and pelvis and femur morphology (as obtained from computed tomography (CT)) in contributing to sex differences in hip adduction during running. Based on existing literature, we hypothesized that females would exhibit lower hip abductor torque production, but similar hip abductor activation during running when compared to males. In addition, we hypothesized that when compared to males, females would exhibit differences in pelvis and femur morphology that would be suggestive of higher degrees of hip adduction during running (i.e., greater pelvis width relative to femur length, lower acetabulum abduction and femoral neck-shaft angles, and greater acetabulum anteversion and femoral anteversion angles).

Lastly, we hypothesized that measures of pelvis and proximal femur morphology would explain a greater amount of the variance in hip adduction during the late swing and stance phases of running compared to hip abductor strength and activation.

METHODS

Participants

Twenty-nine recreational runners participated in this study (14 males and 15 females; **TABLE 1**). To be eligible for this study, participants must have been between 18-45 years of age, and currently running at least 16 km per week. All participants were natural heel strike runners (e.g., runners who contacted the ground with the rear third of their foot), which was verified using sagittal plane images from high-speed video (120 Hz). Only heel strike runners were recruited owing to the known biomechanical differences among runners with varying foot-strike patterns (29).

Potential participants were excluded if they reported any of the following: 1) women who were pregnant or breastfeeding; (2) current lower extremity pain; 3) previous history of lower extremity surgery, fracture, osteoarthritis, hip dysplasia, or 4) any lower extremity condition that resulted in pain or discomfort during running within 6 months prior to participation. An a priori power analysis indicated that 29 participants were sufficient to achieve a statistical power of 80% for a moderate effect size (expected correlations of 0.5) using an alpha level of 0.05.

Procedure

After screening and enrollment, each participant completed 3 phases of data collection: 1) CT of the pelvis and femur, 2) hip abductor strength testing, and 3) instrumented gait analysis. Prior to data collection, participants were informed as to the objectives, procedures, and potential

risks of participation in the study and provided informed consent as approved by the University Health Science Institutional Review Board.

CT Scanning

Pelvis and femur morphology data were obtained using a 320 detector Toshiba Aquilion One CT scanner. Participants were positioned supine in the CT system with the knees extended. The lower limbs were stabilized in a neutral position to avoid hip external rotation and abduction. Axial plane images of the pelvis and both femurs were obtained for each participant (0.5 mm slice thickness, zero tilt, 100 mA, and 80 kVp). By using a low mA and kVp with iterative reconstruction processing, participant exposures were in the sub-millisievert range or less than 4 months of background radiation equivalent.

Hip Abductor Strength Testing

Hip abductor strength of each participant's dominant leg (defined as the leg preferred to kick a ball) was measured using a Cybex dynamometer (Computer Sports Medicine Inc., Stoughton, MA). The dynamometer provided torque values in Nm, with a precision of 0.02% (full scale). The sampling frequency was 100 Hz.

Electromyographic (EMG) signals of the gluteus medius were obtained during the strength testing trials for normalization purposes. Surface electrodes were placed over the gluteus medius at the midpoint between the iliac crest and greater trochanter (30). EMG signals were collected at a sampling rate of 3000 Hz using a Noraxon Telemetry DTS EMG system (Noraxon Inc, AZ, USA). The system had a differential input impedance of greater than 100 MOhm and a common-mode rejection ratio greater than 100 dB.

Participants were positioned side-lying with the axis of the dynamometer aligned with the hip joint center. The resistance pad was positioned just proximal to the lateral knee joint line and

secured to the distal thigh with straps. Three trials of 5-second maximal efforts were performed with a one-minute break between trials. Verbal encouragement was given throughout testing. Hip abductor strength was quantified by averaging the peak hip abduction torques obtained from the three trials. Torque values were normalized to body mass.

Instrumented Running Analysis

Three-dimensional lower extremity kinematics during running were collected using an 11-camera motion capture system (Qualisys, Gothenburg, Sweden) at a sampling rate of 250 Hz. Ground reaction force data were obtained at a rate of 1500 Hz using a single force plate (AMTI, Newton, MA).

Prior to data collection, 21 anatomical markers (reflective 14-mm diameter) were placed on the following bony landmarks: distal phalanges of second toes, first and fifth metatarsal heads, medial and lateral malleoli, medial and lateral epicondyles of femurs, greater trochanters, iliac crests, L5-S1 junction, and anterior superior iliac spines (ASISs). In addition, marker clusters mounted on semi-rigid plastic plates were placed on the back of the sacrum and the lateral surfaces of the participant's thighs, shanks, and heel counters of the shoes. A standing calibration trial was first obtained to define the segmental coordinate systems and joint axes. After the calibration trial, anatomical markers were removed, except for those at the ASISs, iliac crests, and L5-S1 junction.

Following marker placement participants were instructed to run overground along a 14-meter runway at a controlled speed of 4 m/s. A successful trial was defined when the running speed was within $\pm 5\%$ of the target speed and the foot of the dominant leg fell within the borders of the force plate from initial contact to toe-off. A total of 3 successful trials were collected from each participant's dominant leg. Kinematic, kinetic, and EMG data were collected and synchronized using a motion capturing software (Qualisys Track Manager version 2.12).

Data Analysis

Morphology Measurements

Using a commercial software package (Avizo, FEI Visualization Sciences Group, USA), CT slices of pelvis and femur were separately segmented, reconstructed, and smoothed to derive 3D subject-specific pelvis and femur geometry models. Manually selected landmarks were identified on each model (anterior superior iliac spines, pubic symphysis, 32 evenly spaced points along the acetabulum rim, medial and lateral femoral epicondyles, and the point immediately inferior to lesser trochanter). In addition, regions of femoral head and femoral head-neck junction were also manually selected from the 3D femur model for purposes of defining femoral head center and femoral head-neck axis, respectively. Next, the models and selected landmarks were imported into MATLAB software (MathWorks Inc., MA, USA) to acquire the structural measurements of interest from the dominant leg.

To obtain measures of acetabulum orientation, the pelvis coordinate system (**FIGURE 1a**) was first defined. The frontal plane was determined as the plane passing through the bilateral ASISs and pubic symphysis. The transverse plane was defined as the plane containing bilateral ASISs and perpendicular to the frontal plane. The sagittal plane was then defined as the plane passing through the pubic symphysis and perpendicular to both frontal and transverse planes.

Following establishment of the pelvis coordinate system, the acetabulum face plane was defined as the best fit plane of the selected bony points along acetabulum rim using a least square plane fitting algorithm (**FIGURE 1b**). A vector perpendicular to the acetabulum face plane was created to represent the acetabulum orientation vector (**FIGURE 1b**). Acetabular abduction was measured as the acute angle between the sagittal plane of the pelvis and the projection line of the acetabulum orientation vector onto the frontal plane of the pelvis (**FIGURE 1c**). Acetabular

anteversion was measured as the angle between the frontal plane of the pelvis and the projection line of the acetabulum orientation vector onto the transverse plane of the pelvis (**FIGURE 1d**).

To evaluate proximal femur orientation, the femur coordinate system (**FIGURE 2a**) was first defined. The frontal plane of the femur was defined by the plane tangent to the posterior surface of the femur. Similarly, the transverse plane was defined by the plane that was tangent to the inferior surface of the femur. The sagittal plane was then defined as the plane perpendicular to both the frontal and transverse planes.

The femoral head-neck axis was created using a consecutive ellipse fitting algorithm (31) (**FIGURE 2b**). The femoral shaft axis was determined by the first principal component vector determined from all cloud points of the shaft surface below the lesser trochanter and above femoral condyles (**FIGURE 2b**). The femoral neck-shaft angle was then measured as the obtuse angle between the projected lines of femur head-neck axis and femur shaft axis onto the frontal plane of femur (**FIGURE 2c**). Femoral anteversion was measured as the angle between the frontal plane of femur and the projection line of the femoral head-neck axis onto the transverse plane of femur (**FIGURE 2d**).

As an indicator of pelvis width, the linear distance between the left and right hip joint centers was measured. The femoral head centers were defined as the center of a sphere fit to the respective femoral head surface models. The bilateral hip width distance was normalized to femur length of the dominant leg, which was defined as the linear distance between the femoral head center and the midpoint between medial and lateral epicondyles.

EMG Activity

Raw EMG signals obtained from gluteus medius during the strength testing and running trials were processed in MATLAB software (MathWorks Inc., MA, USA). EMG data were band-

pass filtered at 20 to 450 Hz and smoothed using a 100 ms window (32). Maximum activation of gluteus medius was determined as the peak value from the three strength trials. EMG data during running were then normalized to the peak value and expressed as a percentage of maximum voluntary isometric contraction (% MVIC).

Muscle activity of gluteus medius was quantified during two phases of the running cycle: late swing and stance. Late swing phase muscle activation was quantified as the average activity 100 ms prior to peak hip adduction. Stance phase muscle activation was quantified as the average EMG activity from initial contact and peak hip adduction. Data obtained from the three successful trials were averaged for statistical analysis.

Hip Kinematics

Visual 3D software (C-Motion, Rockville, MD) was used to quantify 3D kinematics of the dominant leg during running. Motion trajectory data were low pass filtered at 20 Hz using a 4th order Butterworth filter (33). Joint kinematics were calculated using Cardan angles with a rotation sequence of flexion/extension, abduction/adduction, and internal/external rotation (34). Hip joint angles were calculated as the motion of the femur relative to pelvis. Peak hip adduction during the late swing phase and stance phase was identified for each trial. Data obtained from the three successful trials were averaged for statistical analysis.

Statistical Analysis

Independent sample t-tests were used to compare sex differences in hip abductor strength, gluteus medius activation (stance and swing), and the morphology variables of interest. Multiple linear regression was used to evaluate the ability of each independent variable of interest to predict peak hip adduction during late swing and stance. For each analysis, we first tested for the presence of a sex interaction, if no interaction was present, males and females were combined in the final

regression model. Otherwise, potential relationship in each sex group was analyzed separately. All statistical analyses were performed using R Statistical Software (version 3.6.3; R Foundation for Statistical Computing, Vienna, Austria), using significance level $\alpha=0.05$.

RESULTS

Time series data for frontal plane hip motions during running are presented in **FIGURE 3**. Compared to males, females exhibited significantly greater peak hip adduction during both the late swing phase ($8.5 \pm 2.6^\circ$ vs $6.2 \pm 2.8^\circ$, $p = 0.04$) and stance phase of running ($13.4 \pm 4.2^\circ$ vs $10.0 \pm 3.2^\circ$, $p = 0.02$).

Descriptive data for each of the predictor variables of interest for both males and females are presented in **TABLE 2**. Compared to males, females exhibited significantly lower hip abductor torque production than males ($p=0.04$, **TABLE 2**). Of the morphology variables examined, femoral neck-shaft angle ($p=0.01$, **TABLE 2**) and the bilateral hip width to femur length ratio ($p=0.03$, **TABLE 2**) were significantly larger in females than in males. There were no significant sex differences in hip abductor muscle activation or any other morphological variables of interest.

Predictors of Late Swing Phase Peak Hip Adduction

No sex interactions were identified for any of the regression models related to the prediction of late swing phase peak hip adduction angles ($p>0.05$). As such, data for males and females were combined in each model. Femoral anteversion was found to predict late swing phase hip adduction ($p=0.03$, **TABLE 3**, **FIGURE 4a**). No other variables of interest were found to be predictive of peak hip adduction during this phase.

Predictors of Stance Phase Peak Hip Adduction

A significant sex interaction effect was identified for gluteus medius activation ($p<0.05$).

As such, males and females were considered separately. Gluteus medius activation was not predictive of stance phase peak hip adduction in either sex group ($p>0.05$, **TABLE 3**). There were no significant sex interactions identified in the remaining linear regression models ($p>0.05$). For males and females combined, only the femoral anteversion angle was predictive of peak stance phase hip adduction ($p = 0.01$, **TABLE 3**, **FIGURE 4b**). No other variables of interest were predictive of peak hip adduction during the stance.

DISCUSSION

The purpose of the current study was to comprehensively evaluate the influence of pelvis and femur morphology, hip abductor strength, and muscle activation on hip adduction during the late swing and stance phases of running. For all variables examined, only femoral anteversion was predictive of peak hip adduction during the late swing and stance phases of running. Our findings highlight the difficulty in predicting movement behavior during complex motor tasks using simple measures of muscle performance and skeletal structure.

Of the five morphology variables examined, sex differences were only found for the bilateral hip width to femur length ratio and femoral neck-shaft angle. With respect to our finding of higher hip width to femur length ratio, there is evidence that females have a greater bilateral acetabulum distance and a shorter femur length compared to males (35). The finding of a greater femoral neck-shaft angle in females is consistent with previous studies (36-39) but not all (35,39-41). Inconsistent findings among studies can be attributed to differences in sample sizes and populations evaluated, as the femoral neck-shaft angle has been reported to decrease with age (36) and physical activity levels (42).

As for measures of acetabulum abduction, acetabulum anteversion, and femoral anteversion, we did not find statistical differences between males and females. Our findings are in

agreement with previous studies (35,43,44) but in contrast to others that have reported significant sex differences in acetabulum abduction (45-47), acetabulum anteversion (40,44-47), and femoral anteversion (38,40). Inconsistent findings in literature could be a result of different methodologies used to obtain morphological measurements (2D vs 3D). In addition, the age of populations examined may be a contributing factor as it has been shown that pelvis morphology differs between females and males between post-puberty and pre-menopause but are similar otherwise (48).

Regarding the ability of the morphology variables of interest to predict peak hip adduction during running, only femoral anteversion emerged as a predictor during late swing and stance. It is important to note however that only 13% and 16% of the variance in peak hip adduction was explained by femoral anteversion for the late swing and stance phases, respectively. The fact that a transverse plane morphology variable was found to be predictive of frontal plane motion highlights the potential of an inter-planar influence of femur morphology on joint kinematics. This premise of inter-planar influence of femur morphology measurements on lower limb kinematics is supported by a previous study that reported persons who exhibit greater femoral anteversion also exhibit greater degrees of frontal plane knee motion during single-leg landing tasks (23). This inter-planar relationship between morphology and hip kinematics also could be due in part to the crosstalk that can occur between the frontal and transverse plane hip joint angles when calculated using Cardan angles (49).

Theoretically, a smaller femoral neck-shaft angle would have the potential to bias the hip into greater adduction. In contrast to this assumption, females exhibited greater femoral neck-shaft angles despite displaying greater degrees of hip adduction than males. The finding that the femoral neck-shaft angle was not predictive of peak hip adduction is in agreement with Baggaley et al. (26) who also did not find a relationship between the femoral neck-shaft angle and hip adduction in

female runners.

Apart from the morphology measurements, we also examined the potential influence of hip abductor muscle strength on sex differences in hip adduction during running. Our finding of lower hip abductor strength in females compared to males is consistent with previous literature (12-14). The lack of predictive ability of hip abductor strength to explain hip adduction during running also agrees with previous studies that involved both female and male participants (17-21). Taken together, the findings of the current study and previous work in this area, call into question the influence of hip abductor strength on hip adduction during running.

Lastly, our EMG results related to gluteus medius neuromuscular recruitment revealed similar levels of activation between males and females during the late swing and stance phases of running. This finding is consistent with previous studies in this area (18,22). In addition, gluteus medius activation was not predictive of stance phase hip adduction, which is in agreement with results of Chumanov et al. (19). Similar to hip abduction strength, our results call into question the role of hip abductor activation in contributing to hip adduction during running.

Several limitations need to be considered when interpreting the results of this study. First, the participants in our study were young, healthy, recreational runners. Caution is needed when generalizing results of this study to various clinical populations in which greater degrees of hip adduction may be expected (i.e., runners with patellofemoral pain or iliotibial band syndrome). In addition, a larger sample size would be required to detect sex differences in several of the morphology variables examined. Last, we only examined a few of the more common pelvis and femur morphological variables in this study. Further exploration of other morphology variables in relation to hip adduction during running is indicated.

CONCLUSION

Hip abductor muscle strength and gluteus medius activation were not predictive of frontal plane hip kinematics during running. In contrast, femoral anteversion was predictive of peak hip adduction during late swing and stance phases of running. Our results provided much-needed knowledge and evidence in the importance of femur morphology, as opposed to hip abductor strength and activation, in contributing to sex differences in hip adduction during running. However, the fact that only a small amount of the variance in peak hip adduction could be explained by femoral anteversion highlights the complexity of predicting joint kinematics based on traditional measures of morphology. Future studies in this area should future explore the inter-planar interaction effects of morphologic measures on sex differences in hip adduction during running.

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There is no conflict of interest to disclose. The results of the present study do not constitute endorsement by ACSM. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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471 **FIGURES**

472 **FIGURE 1.** Pelvis morphology measurements. (a) pelvis coordinate system, (b) acetabulum face
473 plane and acetabulum orientation vector, (c) acetabular anteversion angle, (d) acetabular abduction
474 angle.

475 **FIGURE 2.** Proximal femur morphology measurements. (a) femoral coordinate system, (b)
476 femoral head-neck and shaft axes, (c) femoral neck-shaft angle, (d) femoral anteversion angle.

477 **FIGURE 3.** Sex difference in frontal plane hip motion during running. Data are mean $\pm$ SD.

478 **FIGURE 4.** Scatterplot of femoral anteversion and peak hip adduction during the late swing phase
479 (a) and stance phase (b) of running. Orange dots represent females, and green dots represent males.

TABLE 1. Participant demographics

	Females	Males
	(n=15)	(n=14)
Age (years)	25.2 ± 3.4	26.2 ± 4.5
Height (m)*	1.7 ± 0.1	1.8 ± 0.1
Weight (kg)*	59.2 ± 8.5	76.7 ± 8.6
Running distance (km/week)	25.3 ± 9.2	36.3 ± 30.7

Values are mean ± SD. *: significant sex difference, $p < 0.05$

TABLE 2. Sex differences among the variables of interest.

Variables	Females (n=15)	Males (n=14)	p-value	effect size
Hip Abductor Strength (Nm/kg)	1.8 ± 0.3	2.0 ± 0.3	0.04*	0.70
Late Swing Gluteus Medius Activation (% MVIC)	16.5 ± 6.6	15.7 ± 8.1	0.33	0.11
Stance Phase Gluteus Medius Activation (% MVIC)	50.8 ± 17.8	46.8 ± 15.7	0.39	0.24
Acetabulum Abduction Angle (°)	50.6 ± 3.1	49.9 ± 5.0	0.34	0.16
Acetabulum Anteversion Angle (°)	21.6 ± 6.4	19.8 ± 5.5	0.21	0.30
Femoral Neck Shaft Angle (°)	134.1 ± 5.0	129.9 ± 4.1	0.01*	0.91
Femoral Anteversion Angle (°)	14.7 ± 10.6	11.9 ± 8.2	0.21	0.30
Bilateral Hip Width/Femur Length	0.44 ± 0.02	0.42 ± 0.03	0.03*	0.77

Values are mean ± SD. *: significant sex difference, $p < 0.05$

TABLE 3. Predictors of peak hip adduction during the late swing and stance phases of running.

Variables	Peak Hip Adduction			Peak Hip Adduction		
	Late Swing			Stance		
	r	R ²	p-value	r	R ²	p-value
Hip Abductor Strength	-0.27	0.07	0.16	-0.08	0.01	0.69
Gluteus Medius Activation	0.05	0.03	0.80	F: 0.50	0.25	F: 0.06
				M: -0.43	0.19	M: 0.14
Acetabulum Abduction Angle	-0.09	0.01	0.33	-0.16	0.03	0.20
Acetabulum Anteversion Angle	-0.08	0.01	0.35	0.02	<0.01	0.46
Femoral Neck Shaft Angle	0.24	0.06	0.10	0.03	<0.01	0.43
Femoral Anteversion Angle	0.36	0.13	0.03*	0.41	0.16	0.01*
Bilateral Hip Width/Femur Length	0.12	0.02	0.26	0.26	0.07	0.09

F: Females, M: Males. *: significant correlation, $p < 0.05$

FIGURE 1. Pelvis morphology measurements. (a) pelvis coordinate system, (b) acetabulum face plane and acetabulum orientation vector, (c) acetabular anteversion angle, (d) acetabular abduction angle.

FIGURE 2. Proximal femur morphology measurements. (a) femoral coordinate system, (b) femoral head-neck and shaft axes, (c) femoral neck-shaft angle, (d) femoral anteversion angle.

FIGURE 3. Sex differences in frontal plane hip motion during running. Data are mean $\pm$ SD.

FIGURE 4. Scatterplot of femoral anteversion and peak hip adduction during the late swing phase (a) and stance phase (b) of running. Orange dots represent females, and green dots represent males.