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Relationship Between Eccentric Hip Torque and Lower-Limb Kinematics: Gender Differences

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The purposes of this study were to compare lower-limb kinematics between genders, and determine the relationships among eccentric hip abductor and lateral rotator torques and lower-limb kinematics. The movements of the pelvis, femur, and knee were calculated for 16 women and 16 men during the single-leg squat. Eccentric hip abductor and lateral rotator torques were measured using an isokinetic dynamometer. The results showed that women had greater contralateral pelvic depression, femur adduction, and knee abduction than men. The eccentric hip abductor and lateral rotator torques were correlated with coronal plane femur and knee movements in the overall sample. When the genders were analyzed separately, it was observed that women with greater eccentric hip abductor torque exhibited less femur adduction and femur medial rotation, and greater knee adduction excursion. No significant relationship was observed between the isokinetic and kinematic variables in the male group. The differences between the genders help to explain the greater rate of knee disorders observed in women. Moreover, the eccentric hip abduction action seemed to be more important in women to control the lower-limb movements.

Keywords: biomechanics, isokinetic, motion analysis

Most injuries observed in sports medicine affect the knee joint, and patellofemoral pain syndrome (PPS) is one of the most common knee overuse syndromes seen in physical therapy outpatient clinics (Taunton et al., 2002). It has been reported that women have a greater incidence of this disorder than men (Boling et al., 2010). Recently, much research has been carried out to determine the factors responsible for this disparity in knee injuries between genders (Malinzak et al., 2001; Zeller et al., 2003; Ford et al., 2005).

Several studies have verified greater knee abduction excursion in women during some functional activities such as single-leg squat (Willson et al., 2006; Zeller et al., 2003), cutting maneuvers (Ford et al., 2005; Malinzak et al., 2001), and landing (Ford et al., 2006; Jacobs et al., 2007; Kernozek et al., 2005; Russell et al., 2006). Moreover, some studies have found greater hip adduction and medial rotation excursions in women during walking (Hurd et al., 2004) and running (Ferber et al., 2003; Chumanov et al., 2008). Poor control of these movements in weight-bearing activities may increase the quadriceps angle and, consequently, patellofemoral stress (Powers, 2003). Patellofemoral pain syndrome is a common complaint in the sporting and general populations, especially when repetitive lower-limb loading is involved (Cowan et al., 2002). This condition is especially common among female athletes and is traditionally associated with abnormal lower-extremity mechanics thought to increase retropatellar stress (Powers, 2003). Although running or walking as a model for repetitive injury may seem more appropriate to explain this condition, there are various studies in the literature that used other activities with lower demand to associate with the occurrence of PPS. For example, Willson and Davis (2008) examined hip and knee kinematics in subjects with and without PPS during progressively challenging tasks, which included the single-leg squat, running, and repeated single-leg jumping. Subjects with PPS exhibited greater hip adduction than the controls in all the tasks performed. The authors suggest that females with PPS seem to show similar abnormal lower-extremity mechanics across a variety of activities. The authors reported that females with PPS did not employ different lower-limb alignments as the demand of the activity increased. Since 85% of patients with PPS have pain during squatting (Post and Fulkerson, 1994), we believe that a single-leg squat may be a good model for a repetitive injury study.

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Factors proximal to the knee including weakness of the hip abductors and lateral rotator muscles have been associated with excessive femoral adduction, femur medial rotation, and contralateral pelvic depression (Jacobs et al., 2007; Souza & Powers, 2009; Mascal et al., 2003). However, there is no consensus in the literature about the role of these hip muscles in controlling lower-limb movements (DiMattia et al., 2005; Jacobs & Mattacola, 2005; Claiborne et al., 2006; Willson et al., 2006; Jacobs et al., 2007; Thijs et al., 2007; Wallace et al., 2008; Hollman et al., 2009). Methodological differences related to strength evaluation procedures and sample profile may have contributed to the different findings.

Although the hip abductor and lateral rotator muscles must act eccentrically to control excessive femur adduction, femur medial rotation, and contralateral pelvic depression during functional weight-bearing activities (Ferber et al., 2003), most studies have measured the isometric strength of this musculature (DiMattia et al., 2005; Willson et al., 2006; Jacobs et al., 2007; Thijs et al., 2007; Wallace et al., 2008; Hollman et al., 2009). Furthermore, several studies have used a sample regardless of gender (DiMattia et al., 2005; Claiborne et al., 2006; Willson et al., 2006; Thijs et al., 2007). Ferber et al. (2003) showed that greater eccentric demand is placed on the hip abductor muscles of women during the stance phase of running when compared with that of men. Thus, an eccentric evaluation of the hip muscles, considering the genders separately, could possibly show the true relationship between the strength of the hip muscles and lower-limb kinematics.

Therefore, the purposes of this study were (a) to compare lower-limb kinematics between genders during the single-leg squat and (b) determine the relationships between eccentric hip abductor and lateral rotator torques and lower-limb kinematics in both genders. The single-leg squat was chosen because it is a very simple weight-bearing functional test commonly used in the clinical setting and has also been used in other studies (Claiborne et al., 2006; Willson et al., 2006; Zeller et al., 2003). It was hypothesized that women, when compared with men, will exhibit (a) greater contralateral pelvic depression, femur adduction, femur medial rotation, and knee abduction excursions during the single-leg squat and (b) greater correlation coefficients between the isokinetic and kinematic variables studied.

Methods

Sixteen male (mean ± *SD*; age, 21.8 ± 2.8 years; height, 177.0 ± 6.4 cm; body mass, 75.7 ± 9.0 kg) and 16 female (age, 20.5 ± 1.7 years; height, 164.6 ± 6.0 cm; body mass, 57.8 ± 10.1 kg) recreational athletes participated in this study. A recreational athlete was defined as anyone participating in aerobic or athletic activity at least three times per week (Heinert et al., 2008). Anyone with current injury or previous surgery in the lower limb, or who had cardiovascular, pulmonary, neurological, or systemic conditions that limited physical activity, were excluded from the study. All subjects read and signed an informed consent form before the assessments, and all testing procedures were approved by the university's ethical committee.

Kinematic Assessment

After the physical evaluation, a kinematic assessment of the dominant lower limb was carried out during the single-leg squat. For each subject, the dominant lower limb was determined by asking which leg they would use to kick a ball as far as possible. The trials were recorded using four digital cameras (Panasonic NV-GS180) adjusted to the acquisition frequency of 60 Hz, positioned so they could capture all the passive markers and located in front of (Cameras 1 and 2) and posterolaterally (Cameras 3 and 4) to the subjects. The frontal cameras presented a 60° angle between them, whereas Cameras 3 and 4 were angled 60° to the subject (120° between them). For calibration, an object (1 m × 1.8 m × 0.8 m) was filmed in the area where the subjects would perform the single-leg squat. This object had 24 control points with known absolute positions in relation to the Cartesian coordinate system. The global reference system was then defined with this calibrated object, in which the *Y*-axis was oriented upwards, the *X*-axis anteriorly, and the *Z*-axis to the right of the subjects (Wu & Cavanagh, 1995).

In each evaluation, nine passive reflective markers (10 mm in diameter) were positioned by the same researcher at the following anatomical landmarks: both anterior superior iliac spines, first sacral vertebra, prominence of the greater trochanter, lateral and medial epicondyle of the femur, head of the fibula, lateral and medial malleolus. This marker distribution was necessary for the recording of the static standing position of the subjects as well as to determine the lower-limb alignment during the single-leg squat. The raw marker coordinates were tracked using the software Dvideow (Digital Video for Biomechanics for Windows 32 bits) (Figueroa et al., 2003), which uses the direct linear transformation method for 3D representation (Abdel-Aziz & Karara, 1971).

The single-leg squat test was carried out by each subject for analysis of the lower-limb kinematics. The subjects were instructed to stand with the contralateral lower limb off the floor and with their arms crossed in front of the thorax. The static standing trial was registered in this position and used to determine the lower-limb anatomical position. This static measurement was used as the neutral alignment for each subject, with subsequent measurements referring to this position. The subjects were asked to squat as from this position to approximately 75 degrees of knee flexion, and then return to the starting position (Figure 1). An adjustable support was placed beside the subjects at a height that represented the distance from the floor to the greater trochanter of the femur mark necessary to achieve the established knee flexion angle (Willson et al., 2006). The execution time of the single-leg squat was standardized at 2 ± 0.3 s, controlled by a progressive digital stopwatch. Each subject completed three attempts for familiarization and five acceptable trials for the data analysis. If any of the evaluation requirements were not carried out, the attempt was invalidated and a new one performed. The averages of the kinematic values obtained from five acceptable trials were used for the statistical analyses.

After recording the 3D coordinates for each marker, data were submitted to the software Matlab (Mathworks Inc., Natick, MA, USA) and analyzed using a low-pass 4th-order Butterworth filter with a 5-Hz cutoff frequency. Next, the local coordinate systems of the pelvis, femur, and leg were defined and algorithms created to quantify the joint angles. The knee joint angles were calculated with the mathematical convention of Euler angles, using the coordinate system of the distal segment relative to the coordinate system of the proximal segment (Grood & Suntay, 1983). Since the authors believe that isolated movements of the pelvis and femur are capable of altering the patellofemoral stress, the movement excursions of these local coordinate systems were calculated relative to themselves. For this purpose, the local coordinate systems of the pelvis and femur were defined in the static standing trial, and the relative angles were calculated for the subsequent time instants.

Figure 1 — Single-leg squat test.

The kinematic variables studied were as follows: contralateral pelvis depression/elevation and anterior/posterior rotation, femur abduction/adduction and lateral/medial rotation, and knee abduction/adduction. These variables represented the movement excursions that were calculated by subtraction of the values acquired when the knee was at 60° of flexion, from that recorded in the static standing position. By convention, positive kinematic values represented contralateral pelvis elevation and posterior rotation, femur adduction and medial rotation, and knee adduction excursions. The experimental error was verified using a specific accuracy test (Ehara et al., 1997), which demonstrated a system accuracy of 2.8 mm.

Isokinetic Assessment

The evaluations of the eccentric hip abductor and lateral rotator torques were carried out using an isokinetic dynamometer (Biodex Multi-Joint System 2, Biodex Medical Incorporation, New York, NY, USA) from 48 to 96 hr after the kinematic assessment. The dynamometer was calibrated at the start of every day of testing. Before testing, each subject completed a 5-min warm-up procedure on a stationary bicycle, plus stretching of the hip muscles. All the isokinetic assessments were performed by the same evaluator using a protocol similar to that used in previous studies, which showed good intrarater reliability (Nakagawa et al., 2008; Baldon et al., 2009).

Specifically, eccentric hip abductor torque was tested with the subjects in a side lying position. The dominant limb was positioned parallel to the ground in neutral hip flexion/extension and medial/lateral rotation. The contralateral hip and knee were flexed and fixed with straps. Stabilization of the trunk was carried out using a single belt proximal to the iliac crest. The mechanical rotation axis of the dynamometer was aligned with a point representing the intersection of two lines. One line was directed inferiorly from the posterior-superior iliac spine toward the knee, and the other one posteriorly and medially directed from the greater trochanter of the femur toward the midline of the body. The lever arm of the dynamometer was laterally attached to the thigh under test, 5 cm above the base of the patella. The subjects were instructed not to bend their knees during the test. The range of motion of the test was from 0 (neutral) to 30 degrees of hip abduction.

For the eccentric test of the hip lateral rotators muscles, the subjects were placed in the sitting position with their knees and hips flexed at 90 degrees and with the hip of the limb under test placed at 10 degrees of medial rotation. The rotational axis of the dynamometer was then aligned with the center of the patella (long axis of the femur) and the lever arm attached 5 cm above the lateral malleolus using straps. Four belts were used to stabilize the trunk and limb under test, two crossing the trunk, one around the pelvis and one on the distal thigh. The range of motion of the test was from 10 degrees of medial hip rotation to 20 degrees of lateral hip rotation. The angular speed in both hip evaluations was 30 deg/s. Although it is known that the femur moves at higher velocities during sporting maneuvers (Jacobs & Mattacola, 2005), a lower test speed was chosen to increase the isokinetic phase of the test. Due to the small range of motion during the eccentric test of the hip muscles, high isokinetic testing speeds might decrease the time of the isokinetic phase (Grau et al., 2008) and, consequently, underestimate the torque production capacity.

For the familiarization procedure, the subjects performed one series of five submaximal and one series of two maximal reciprocal eccentric contractions, with a 1-min interval between series. After a further 1-min interval, the subjects performed two series of five maximal repetitions with a 3-min rest period between the series. Oral encouragement was provided to stimulate the subjects to produce the maximum torque. To correct for the influence of gravity on the torque data acquired, the limb was weighed before each test according to the instructions found in the manual of the dynamometer, and the results of the test were automatically corrected by the data acquisition software.

The isokinetic variables used in the statistical analyses for calculating the correlation coefficients were eccentric hip abductor and lateral rotator isokinetic peak torques normalized according to body mass ($N \cdot m \cdot kg^{-1}$), which could be from either the first or second series.

Statistical Analyses

All statistical analyses were performed using the Statistica software (version 7.0, StatSoft Inc, Tulsa, OK, USA). Descriptive values (means, standard deviations) for each variable were first obtained. The data were analyzed with respect to their statistical distribution and variance homogeneity using the Shapiro–Wilk *W* and Levene tests, respectively. With respect to the parametric data, Student's *t* test for independent samples was used to verify gender differences. With respect to the nonparametric data, the Mann–Whitney *U* test was used for the comparisons mentioned above. Effect sizes (Cohen's *d*) were calculated to determine the meaningfulness of any differences.

A Pearson product–moment correlation matrix was used to examine relationships between each strength variable and each kinematic variable for both men and women. The *r* values were interpreted using the following guidelines: 0.00–0.19 = none to slight, 0.20–0.39 = low, 0.40–0.69 = modest, 0.70–0.89 = high, and 0.90–1.00 = very high (Weber & Lamb, 1970). To verify the behavior of the variables studied for each gender, the correlation coefficients were calculated for the overall sample and for each group separately. For all statistical tests, a preset alpha level of 0.05 was used.

Results

Women showed greater knee abduction, femur adduction, and contralateral pelvic depression excursions during the single-leg squat, when compared with men. Although it was not significant, women also showed a trend for greater femur lateral rotation excursion than men (Table 1). The eccentric hip abductor and lateral rotator isokinetic peak torques normalized according to body mass were greater in men when compared with women (Table 1).

The eccentric hip abductor torque of the women correlated modestly and negatively with the coronal and transversal plane femur movements (Table 2). These negative relationships mean that the greater the eccentric hip abductor torque, the lower the femur adduction (Figure 2) and the femur medial rotation excursions (Figure 3). Women also showed a modest and positive relationship between this isokinetic variable and coronal

Table 1 Descriptive data (mean ± *SD*) and comparison between genders

Variables	Women	Men	*p*	Cohen's *d*
Contralateral pelvis excursion†				
Depression (–)/elevation (+)*	–4.80 ± 2.37	–2.43 ± 2.07	0.005	1.1
Anterior (–)/posterior (+) rotation	–2.25 ± 3.38	–1.06 ± 2.70	0.27	0.4
Femur excursion†				
Abduction (–)/adduction (+)*	4.16 ± 2.97	0.01 ± 2.63	<0.001	1.53
Lateral (–)/medial (+) rotation	–2.46 ± 2.46	–0.45 ± 3.54	0.07	0.64
Knee excursion†				
Abduction (–)/adduction (+)*	–4.73 ± 4.84	–0.33 ± 3.48	0.006	1.08
Eccentric hip isokinetic peak torque‡				
Abductor*	1.31 ± 0.15	1.85 ± 0.25	<0.001	2.71
Lateral rotator*	0.80 ± 0.16	1.32 ± 0.15	<0.001	3.46

*Significant gender differences. †Expressed in degrees (°). ‡Expressed in $N \cdot m \cdot kg^{-1}$.

plane knee movements (Table 2). This positive relationship implies that the greater the eccentric hip abductor torque, the greater the knee adduction excursion (Figure 4). In the overall sample, a modest and negative relationship between eccentric hip abductor torque and coronal plane femur movements was observed, and also a modest positive relationship with coronal plane knee movements and a trend for a significant positive relationship with coronal pelvis movements ($p = .06$) (Table 2). The latter relationship implies that the greater the eccentric hip abductor torque, the greater the contralateral pelvic elevation excursions. The eccentric hip abductor torque of the men did not demonstrate any significant relationship with the lower-limb kinematics (Table 2).

The eccentric hip lateral rotator torque correlated modestly and negatively with coronal plane femur movements in the overall sample (Table 3). This negative relationship implies that the greater the eccentric hip lateral rotator torque, the lower the femur adduction excursions. A low and positive relationship with the coronal plane knee movements was also noted in this sample, as well as a modest and positive relationship with the coronal plane pelvis movements (Table 3). These positive relationships implies that the greater the eccentric hip lateral rotator torque, the greater the knee adduction and contralateral pelvic elevation excursions. When the genders were analyzed separately, no significant relationship was observed between eccentric hip lateral rotator torque and the lower-limb kinematics in either of the groups (Table 3).

Discussion

The results of this study demonstrated that women showed greater knee abduction excursion during the single-leg squat than men. This result is in agreement with previous studies showing similar behavior during the execution of the single-leg squat (Willson et al., 2006; Zeller et al., 2003), cutting maneuvers (Ford et al., 2005; Malinzak et al., 2001), and landing (Ford et al., 2006; Jacobs et al., 2007; Kernozek et al., 2005; Russell et al., 2006). It has been suggested that excessive knee abduction overloads the patellar retinaculum and retropatellar

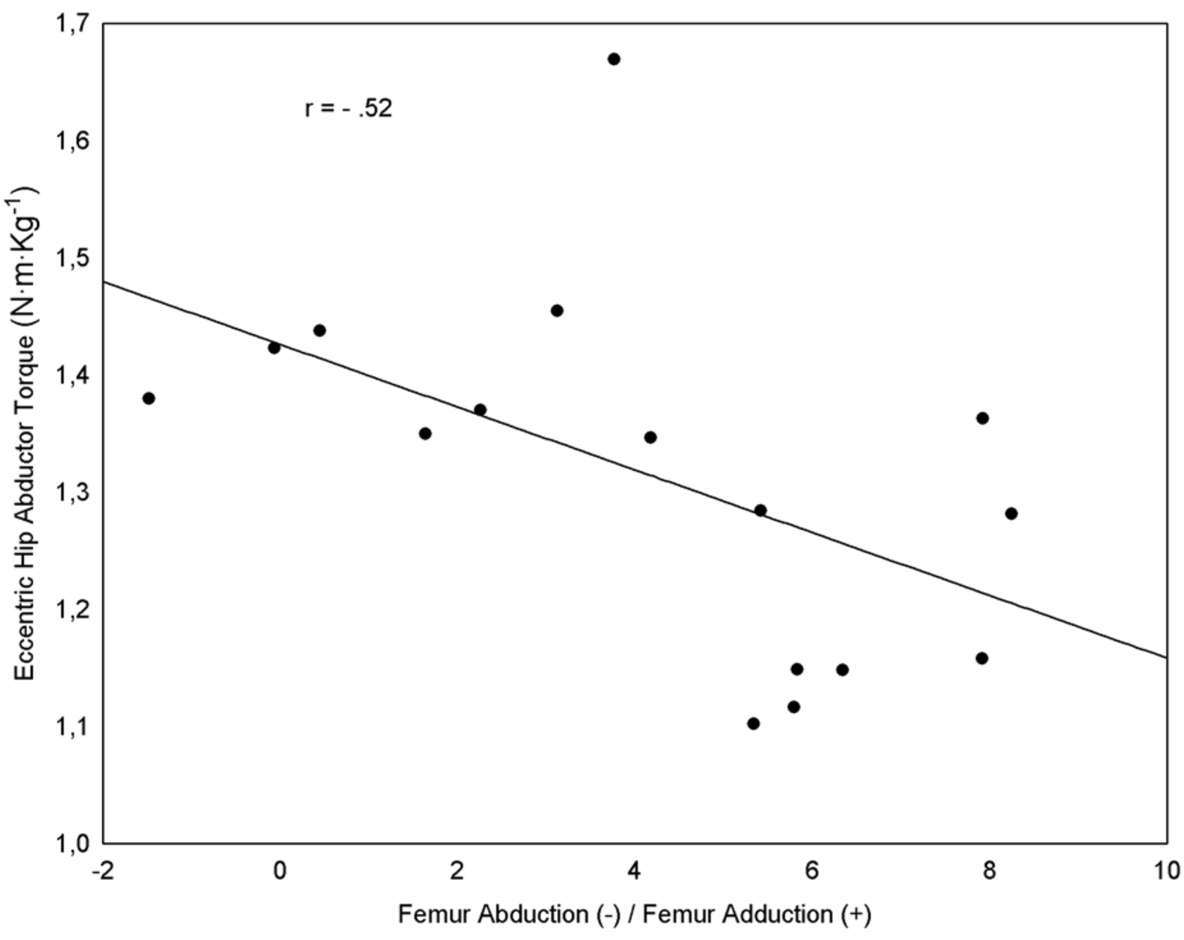

Figure 2 — Eccentric hip abductor isokinetic peak torque normalized according to body mass (N·m·kg^{-1}) versus femur abduction/adduction (degrees) during the single-leg squat in the female group.

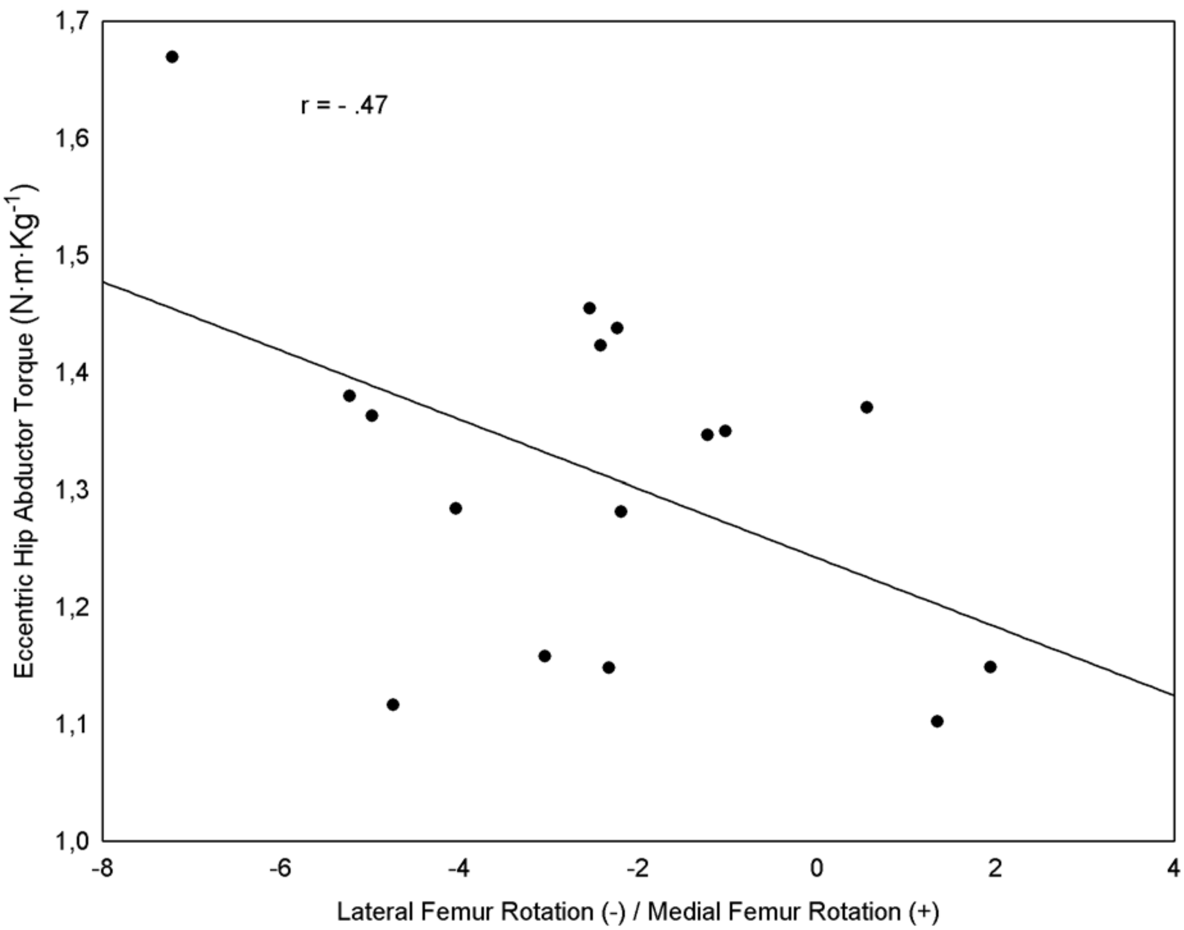

Figure 3 — Eccentric hip abductor isokinetic peak torque normalized according to body mass ($N{\cdot}m{\cdot}kg^{-1}$) versus medial/lateral femur rotation (degrees) during the single-leg squat in the female group.

articular cartilage (Powers, 2003). When performed for a long period of time during weight-bearing functional activities, such as squatting, running, and landing, this knee movement pattern might contribute to patellofemoral misalignment and the development of PPS in women (Powers, 2003).

In addition, it was observed in this study that women showed greater contralateral pelvic depression and femur adduction excursions. Zeller et al. (2003) and Hewett et al. (2006) also reported greater hip adduction during the single-leg squat and landing from a horizontal jump, respectively. Femur adduction movement has been associated with the amount of knee abduction in dynamic weight-bearing activities (Ford et al., 2006; Hollman et al., 2009). These studies demonstrated that when femur adduction is increased, knee abduction is also increased. Therefore, it is possible that the poor control of femur adduction verified in women may contribute to an increase in patellofemoral stress in this gender.

Although it is believed that the hip muscles assist in the control of the pelvis, femur, and knee movements, some studies have shown no correlation between isometric hip abductor strength and coronal plane pelvis, hip, and knee movements (DiMattia et al., 2005; Willson et al., 2006; Thijs et al., 2007; Hollman et al., 2009). The results of the current study suggest that eccentric hip abductor action has significant implications for femur and knee movement controls in women. It was observed that subjects with greater eccentric hip abduction torque showed smaller femur adduction and greater knee adduction excursions, as well as a trend for greater contralateral pelvic elevation.

A possible reason for the differences between the results found in this study and those observed in the literature (DiMattia et al., 2005; Willson et al., 2006; Thijs et al., 2007; Hollman et al., 2009) could be associated with the muscle strength evaluation procedures. During the stance phase of weight-bearing activities, the hip abductor muscles must act eccentrically to control or resist excessive contralateral pelvis depression and femoral adduction (Ferber et al., 2003). Jacobs & Mattacola (2005) reported the same modest relationship

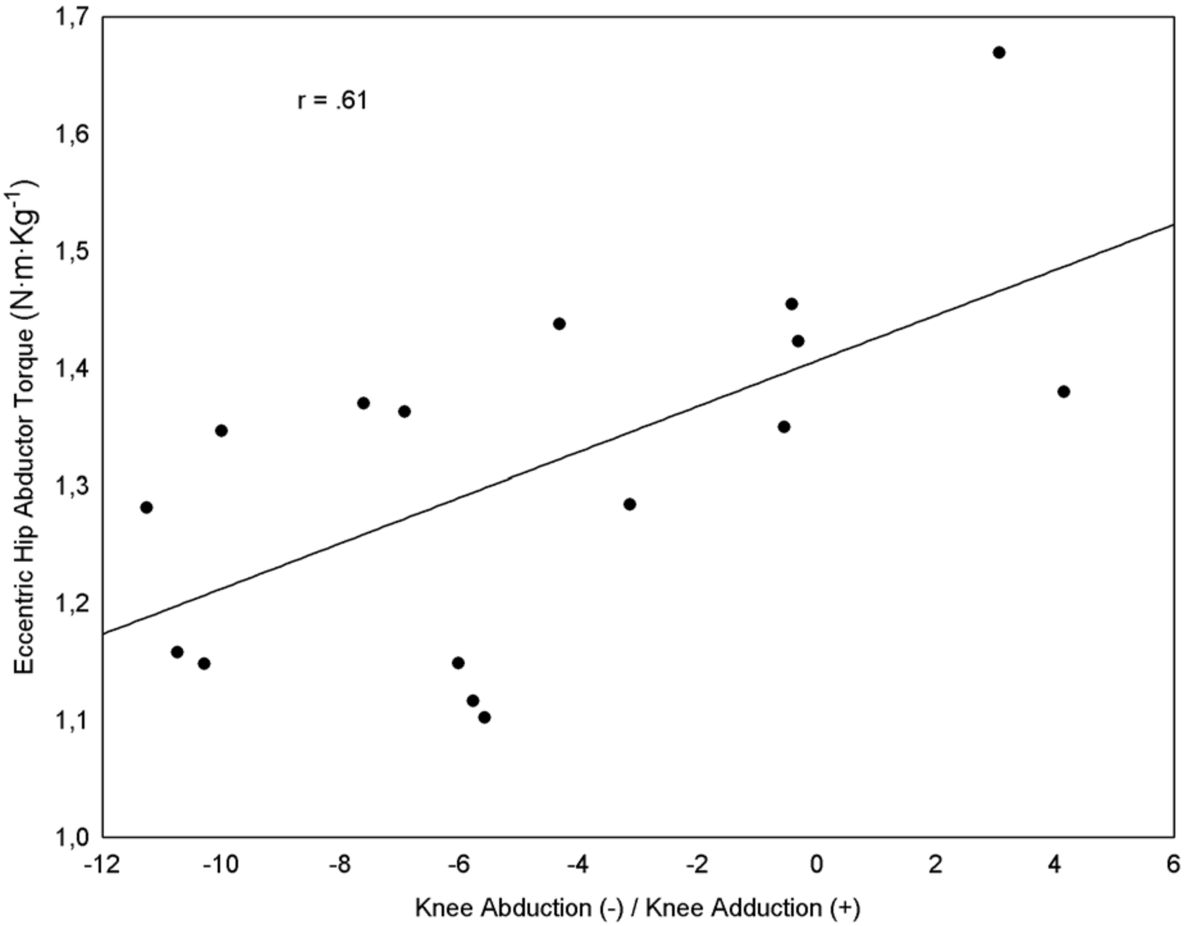

Figure 4 — Eccentric hip abductor isokinetic peak torque normalized according to body mass (N·m·kg^{-1}) versus knee abduction/adduction (degrees) during the single-leg squat in the female group.

Table 2 Pearson product–moment correlation coefficients (*p* values) between eccentric hip abductor torque and lower-limb kinematics

	Pelvis		Femur		Knee
	Coronal Plane	Transversal Plane	Coronal Plane	Transversal Plane	Coronal Plane
Women	0.18 (0.48)	–0.16 (0.55)	–0.52 (0.03)*	–0.47 (0.04)*	0.61 (0.01)*
Men	–0.31 (0.22)	–0.24 (0.35)	0.09 (0.74)	–0.15 (0.56)	–0.07 (0.77)
Overall	0.32 (0.06)	0.04 (0.82)	–0.55 (<0.001)*	0.11 (0.52)	0.49 (0.004)*

*Significant relationship, $p < .05$.

($r = .61$) seen in the current study between eccentric hip abductor torque and knee excursion in women, during landing from a horizontal jump. Thus, the eccentric hip abductor action seems to play a greater role in stabilizing the hip and knee joints when compared with isometric hip abductor strength.

It was also verified in this study that women showed greater correlation coefficients between eccentric hip abductor torque and coronal plane femur and knee movements than men. Similar results were reported by Jacobs et al. (2007) and Wallace et al. (2008). These authors only observed a relationship between isometric hip abductor

Table 3 Pearson product–moment correlation coefficients (*p* values) between eccentric hip lateral rotator torque and lower-limb kinematics

	Pelvis		Femur		Knee
	Coronal Plane	Transversal Plane	Coronal Plane	Transversal Plane	Coronal Plane
Women	0.12 (0.64)	0.32 (0.22)	0.16 (0.52)	–0.21 (0.41)	–0.07 (0.78)
Men	–0.19 (0.46)	–0.12 (0.65)	0.05 (0.82)	0.19 (0.46)	–0.13 (0.61)
Overall	0.40 (0.02)*	0.23 (0.19)	–0.47 (0.006)*	0.28 (0.11)	0.36 (0.04)*

*Significant relationship, $p < .05$.

strength and knee abduction excursion in the female group, during the landing from jump activities. Jacobs and Mattacola (2005) also observed a relationship between eccentric hip abductor torque and knee abduction movement in women only. Ferber et al. (2003) verified that women exhibited greater peak hip adduction angle and hip adduction angular velocity as compared with men during the stance phase of running. As a consequence, women showed greater frontal plane negative work, reflecting in greater eccentric demands placed on the hip abductor muscles. This greater dependence was probably responsible for the greater correlation coefficients observed in the female group in the current study. Women must be more dependent on eccentric hip abduction action to control femur adduction and knee abduction movements, suggesting that a weakness of this muscle group in women may be more decisive in altering lower-limb alignment and causing a greater incidence of PPS in this gender.

Besides the relationships verified between eccentric hip abductor torque and the coronal plane lower-limb movements in women, a correlation was also shown with the transverse plane femur movements in the female group. This result demonstrated that women with greater eccentric hip abductor torque showed lower femur medial rotation excursion. Souza & Powers (2009) reported that the eccentric hip abductor function was an important predictor of femur medial rotation during running. It is known that the main hip abductor strength generator is the gluteus medius, and that this muscle can assist in hip lateral rotation by way of its posterior fibers (Powers, 2010). Greater eccentric hip abductor torque may have reflected by greater gluteus medius strength, explaining the relationships found with transversal plane femur movements. Thus, it is possible that an eccentric deficit of the gluteus medius may increase the femur adduction and secondarily the femur medial rotation.

The eccentric hip lateral rotator torque was correlated with the coronal plane pelvis, femur, and knee movements in the overall sample. These results showed that subjects with greater eccentric hip lateral rotator torque had greater contralateral pelvic elevation and knee adduction as well as lower femur adduction during the single-leg squat. Claiborne et al. (2006) reported a similar correlation coefficient between eccentric hip lateral rotator torque and coronal plane knee movements. It is known that the gluteus maximus is the most powerful lateral rotator of the hip (Powers, 2010). Moreover, the upper portion of this muscle has the ability to abduct the hip, and shows an activation pattern similar to that of the gluteus medius (Lyons et al., 1983). The results of this study suggest that the control of the coronal plane pelvis, femur, and knee movements is provided secondarily by the gluteus maximus. It thus appears that an optimal stabilization of the lower limb in the coronal plane is carried out by a joint action of both the hip abductors and the lateral rotator muscles.

Although no significant difference was observed for gender, women showed a trend to have a greater femur lateral rotation excursion during the single-leg squat, contradicting one of the hypotheses of the authors. In an attempt to minimize the effects caused by the greater femur adduction and knee abduction, increased femoral lateral rotation in women might reflect a compensation mechanism to avoid larger quadriceps angles. Similar to the present results, Zeller et al. (2003) also reported greater hip lateral rotation in women during squatting when compared with men. However, it is possible that women are not able to maintain this compensation during more complex functional activities. Several studies have verified greater hip medial rotation in women during activities such as running (Chumanov et al., 2008; Ferber et al., 2003), landing from a jump (Lephart et al., 2002), and cutting maneuvers (Pollard et al., 2007).

The main findings of this study suggest that women have a lower-limb alignment during the single-leg squat that may contribute to the development of PPS. In addition, women were shown to be more dependent on the abductor muscles to control femur and knee movements. However, due to the slow speeds of both the isokinetic and kinematic evaluations carried out in this study, caution is required to extrapolate these results to sporting activities that are performed at greater speeds. Although it was not the focus of the current study, the results suggest that training emphasizing the eccentric hip abduction and lateral rotation actions could contribute to maintenance of the lower-limb alignment during functional activities, mainly in women. To truly understand the role of the hip abductor and lateral rotator muscles in the neuromuscular control of the lower-limb movements, further prospective investigations should be carried out to determine whether eccentric hip abductor and lateral rotator torque deficits are associated with an increased incidence of PPS.

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