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Gender differences in lower extremity mechanics during running

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Abstract

Objective. To compare differences in hip and knee kinematics and kinetics in male and female recreational runners.

Design. Gait analysis of 20 men and 20 women recreational runners.

Background. Female runners are reported to be more likely to sustain certain lower extremity injuries compared to their male counterparts. This has been attributed, in part, to differences in their structure and it has been postulated that these structural differences may lead to differences in running mechanics. It was hypothesized that females would exhibit greater peak hip adduction, hip internal rotation, knee abduction and decreased knee internal rotation compared to their male counterparts. It was also hypothesized that females would exhibit greater hip and knee negative work in the frontal and transverse planes compared to males.

Methods. Comparisons of hip and knee three-dimentional joint angles and negative work during the stance phase of running gait were made between genders.

Results. Female recreational runners demonstrated a significantly greater peak hip adduction, hip internal rotation and knee abduction angle compared to men. Female recreational runners also demonstrated significantly greater hip frontal and transverse plane negative work compared to male recreational runners.

Conclusion. Female recreational runners exhibit significantly different lower extremity mechanics in the frontal and transverse planes at the hip and knee during running compared to male recreational runners.

Relevance

Understanding the differences in running mechanics between male and female runners may lend insight into the etiology of different injury patterns seen between genders. In addition, these results suggest that care should be taken to account for gender when studying groups of male and female recreational runners.

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Keywords: Male; Female; Running mechanics; Kinematics; Kinetics

1. Introduction

Women runners are reported to be twice as likely to sustain certain running injuries such as patellofemoral pain syndrome, iliotibial band friction syndrome, and tibial stress fractures as compared to their male counterparts (Taunton et al., 2002). It has been postulated that known differences in structure may predispose females to differences in running mechanics which, over many repetitions, may lead to specific injuries. While gender differences in lower extremity structure have been studied, little attention has been devoted to differences in running patterns between men and women.

In terms of structure, Horton and Hall (1989) refute the notion that women have a wider pelvis than men. They do, however, report that women have a larger hip width to femoral length ratio which leads to greater hip adduction. This increased angulation of the femur contributes to the greater static genu valgus that Benas (1984) has reported in women. Women have also been shown to exhibit greater active hip internal rotation than men (Simoneau et al., 1998). The structural combination of increased hip adduction, hip internal rotation, and genu valgus may explain, in part, the larger

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Q-angle that is well-documented in women (Aglietti et al., 1983; Horton and Hall, 1989; Hsu et al., 1990; Livingston, 1998; Woodland and Francis, 1992). An increased Q-angle (the angle subtended by the line connecting the anterior superior iliac spine and the midpoint of the patella and one connecting the midpoint of the patella and the tibial tubercle) has been shown to be associated with an increase in lateral patellar contact forces (Mizuno et al., 2001). Therefore, an increased Q-angle is thought to play a partial role in the greater incidence of patellofemoral disorders that women experience (Almeida et al., 1999; DeHaven and Lintner, 1986; Messier et al., 1991).

The structural differences females exhibit at the hip and knee may predispose them to differences in their movement patterns as well. A few studies have examined gender-related differences in lower extremity mechanics during walking. While Keller et al. (1996) reported no gender-related differences in ground reaction forces (GRF) variables, Li et al. (2001) and Chao et al. (1983) found that women exhibited greater vertical GRF and free vertical moments compared to men. However, the specific joints or planes of motion where the increased torques were expected were not described. In a study of sagittal plane joint mechanics during walking, Kerrigan et al. (1998) reported that women exhibited a significantly greater peak hip flexion angle and negative work compared to men.

Only one study, to date, has addressed differences in lower extremity joint mechanics between genders during running. Malinzak et al. (2001) studied the frontal and sagittal plane motion of the knee in 11 male and 9 female runners. They reported that, while the frontal plane excursion was similar between genders, females exhibited 11° more valgus throughout the stance phase. In addition, women were found to exhibit less peak knee flexion and less knee flexion excursion compared to men. However, these authors did not examine hip kinematics or hip and knee kinetic differences in these subjects.

In summary, little information exists on gender-related differences in the secondary planes of movement for lower extremity running mechanics between genders. Therefore, the purpose of this study was to compare differences in kinematic and kinetic patterns of the hip and knee between male and female runners. The variables of interest were those that may be different between males and females based on documented differences in structure. Therefore, it was hypothesized that females would exhibit greater peak hip adduction, hip internal rotation and knee abduction, but lower peak knee internal rotation (due to the greater femoral internal rotation). It was also hypothesized that females would exhibit greater hip and knee negative work in the frontal and transverse planes compared to their male counterparts.

2. Methods

2.1. Subjects

Based on a priori power analyses ($\beta = 0.20$; $P = 0.05$), 40 recreational runners (20 males and 20 females) between the ages of 18 and 45 years old volunteered for this study. The mean body mass and body height of the male subjects were 82.26 kg (SD 11.79 kg) and 1.81 m (SD 0.06 m), respectively and the female subjects were 59.97 kg (SD 9.25 kg) and 1.67 m (SD 0.07 m), respectively. All subjects were rearfoot strikers free of any obvious lower extremity malalignments or injuries at the time of data collection. Prior to participation, each subject signed a consent form approved by the University's Human Subjects Compliance Committee.

2.2. Procedures

Retro-reflective markers for tracking three-dimensional movement were placed on the thigh, shank, pelvis, and rearfoot (Fig. 1). Anatomical markers defining the joint centers were placed over the following locations: bilateral greater trochanters, medial and lateral femoral condyle, medial and lateral malleoli, heads of the 1st and 5th metatarsals. After a static standing

Fig. 1. Retro-reflective marker placement on the tested lower extremity.

calibration was collected, the anatomical markers were removed and dynamic trials were collected. Subjects ran along a 25 m runway at a speed of 3.65 m/s (±5%) striking a force plate at its center. Running speed was monitored using photoelectric cells placed 2.86 m apart along the runway. Five running trials were collected for the right lower extremity during stance.

2.3. Data collection and analysis

Kinematic data were collected with a passive, 6-camera, 3-D VICON motion analysis system (Oxford Metrics Ltd., Oxford, UK). The cameras were calibrated to a volume of 2.0 m^3 and calibration errors were all below 3 mm. Kinematic data were sampled at 120 Hz and low-pass filtered at 8 Hz with a fourth-order zero lag Butterworth filter. Kinetic GRF data were collected using a force plate (BERTEC Corp, Worthington, OH, USA). GRF data were collected at 960 Hz and low-pass filtered at 50 Hz with a fourth-order zero lag Butterworth filter. Trials were normalized to 100% of stance and five were averaged for each subject. Joint power data were normalized to body mass and height.

MOVE3D software (NIH Biomotion Laboratory, Bethesda, MD, USA) was used to calculate kinematic and kinetic variables. All lower extremity segments were modeled as a frustra of right cones model and anthropometric data provided by Dempster (1959). The kinematic and kinetic variables of interest were extracted from individual trials.

2.4. Statistical design

The kinematic and kinetic variables of interest were selected from the first 60% of the stance phase of gait and included hip and knee sagittal, frontal, and transverse plane peak angles, peak moments, peak angular velocities, and negative work. However, since the primary variables of interest were peak joint angles and negative work, only these variables were statistically analyzed. Peak angles and negative work variables were statistically compared using independent, one-tailed t-tests between males and females at a confidence level of 0.05. Peak joint moments and peak angular velocity values were analyzed descriptively to better understand any differences in peak joint angles and negative work between male and female runners.

3. Results

There were no differences ($P = 0.39$) in stance duration between the male (0.27, SD 0.01 ms) and female (0.26, SD 0.02 ms) recreational runners. Figs. 2–7 present the 3-D angular motions, joint moments, and power patterns of the hip and knee for male and female recreational runners during the stance phase of gait. In the sagittal plane, women runners tended to be in slightly greater hip flexion and produce a great hip extensor moment throughout most of stance but exhibited similar knee joint moment, power, and angular position patterns compared to men (Figs. 2 and 3). Throughout most of the stance phase in the frontal plane, women runners tended to exhibit similar knee and hip joint moment patterns compared to men. However, females demonstrated a greater hip adduction and knee abduction position throughout most of stance and absorbed greater amounts of energy at the hip joint during the first half of stance compared to men (Figs. 4 and 5). In the transverse plane, women runners exhibited similar joint moment patterns as the men but tended to demonstrate a greater hip internal and knee external rotation position and absorb greater amounts of hip and knee energy compared to men (Figs. 6 and 7).

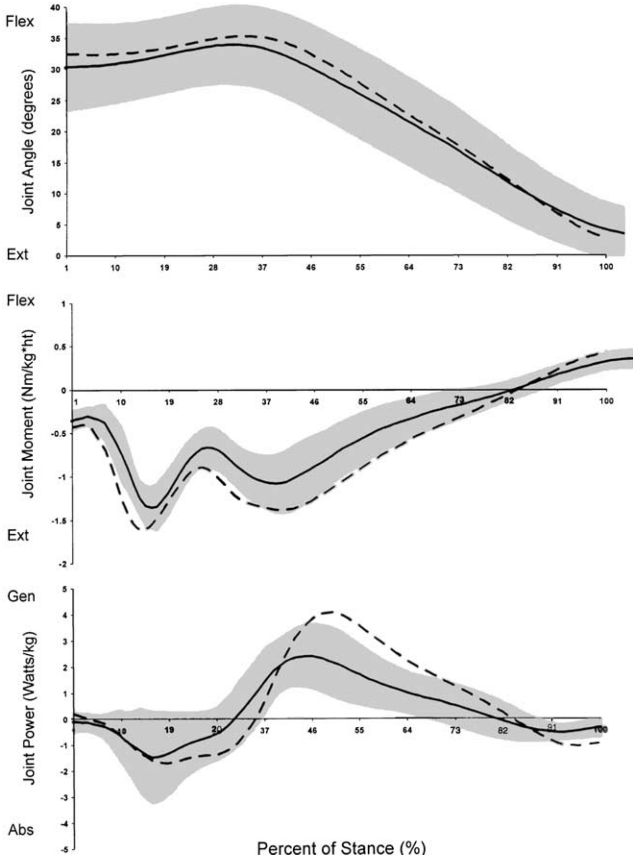

Fig. 2. Hip sagittal plane angular motion (top graph), joint moment (middle graph), and power patterns (bottom graph) for men (solid line is mean, shaded area is ±1 SD) and women (dashed line) during the stance phase of running. Positive values indicate hip flexion, flexor moment, and power generation, negative values indicate hip extension, extensor moment, and power absorption.

Table 1 presents a summary of kinematic and kinetic comparisons of the variables of interest for male and female subjects. In the sagittal plane, no significant differences in peak hip or knee flexion angle ($P > 0.05$),

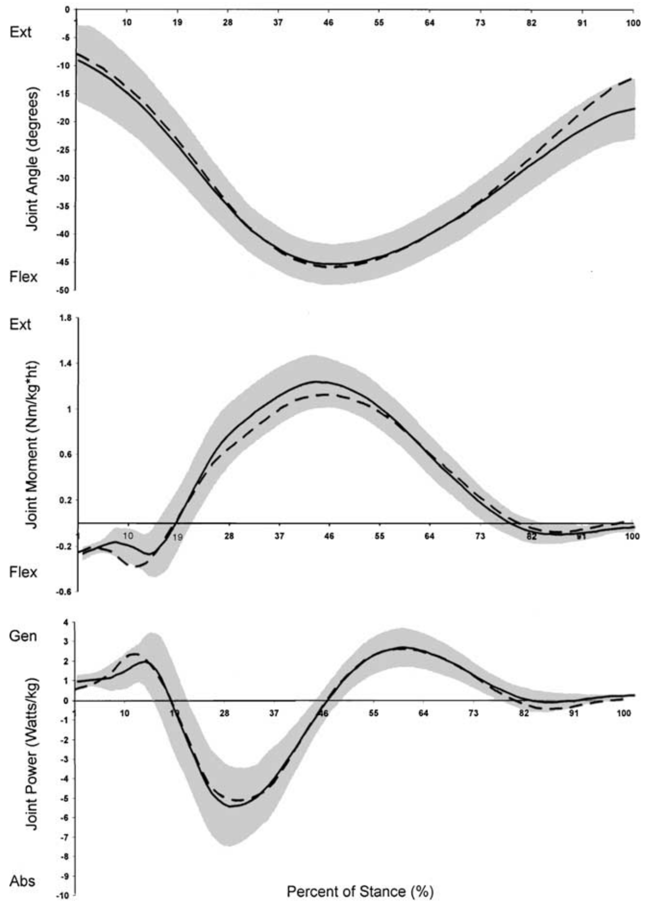

Fig. 3. Knee sagittal plane angular motion (top graph) joint moment (middle graph), and power patterns (bottom graph) for men (solid line is mean, shaded area is ±1 SD) and women (dashed line) during the stance phase of running. Positive values indicate knee extension, extensor moment, and power generation, negative values indicate knee flexion, flexor moment, and power absorption.

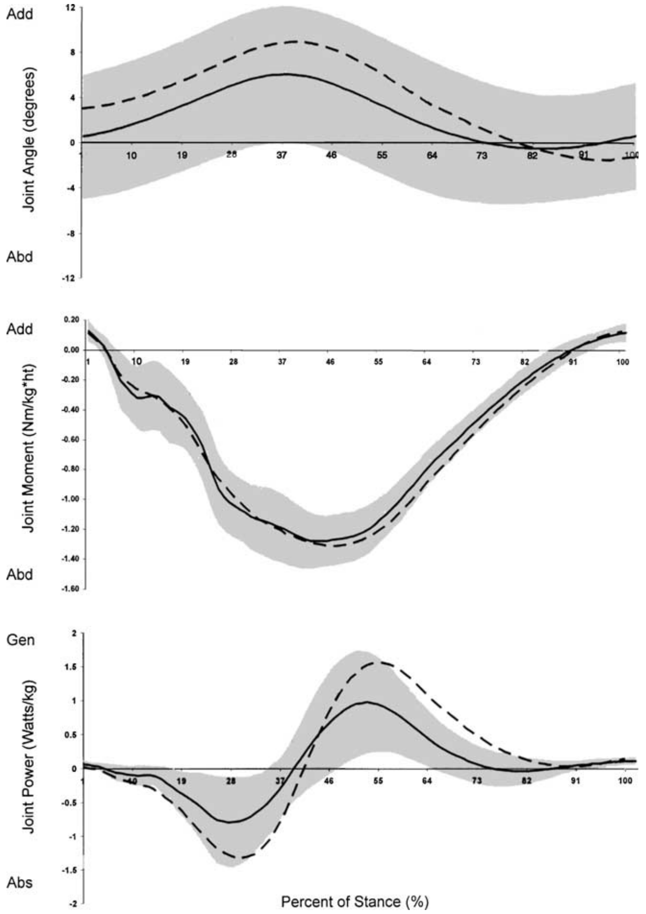

Fig. 4. Hip frontal plane angular motion (top graph), joint moment (middle graph), and power patterns (bottom graph) for men (solid line is mean, shaded area is ±1 SD) and women (dashed line) during the stance phase of running. Positive values indicate hip adduction, adductor moment, and power generation, negative values indicate hip abduction, abductor moment, and power absorption.

negative work ($P > 0.05$), peak flexion velocity, or peak extensor moments were observed between male and female runners. In the frontal plane, female subjects demonstrated a significantly greater peak hip adduction angle ($P < 0.05$), significantly greater hip frontal plane negative work ($P < 0.05$), and greater peak hip adduction velocity but similar peak hip abduction moments compared to men. Also in the frontal plane, females exhibited a significantly greater peak knee abduction angle ($P < 0.05$) but no differences in knee frontal plane negative work ($P > 0.05$), peak abduction velocity, or peak abduction moments. In the transverse plane, females exhibited a significantly greater peak hip internal rotation angle ($P < 0.05$), greater hip transverse plane negative work ($P < 0.05$), and greater peak hip external rotation velocity but no differences in peak hip internal rotation moments compared to men. There were no differences between males and females in knee internal rotation peak angle ($P > 0.05$), transverse plane negative work ($P > 0.05$), peak velocity, or peak joint moments.

4. Discussion

The purpose of this study was to compare differences in kinematic and kinetic patterns of the hip and knee in male and female recreational runners. No differences in sagittal plane hip and knee kinematics or kinetics were observed between male and female recreational runners in the present investigation (Figs. 2 and 3). While Kerrigan et al. (1998) reported that women exhibited significantly greater peak hip flexion and negative work during walking, these differences were not evident during running in the present investigation. In addition, Malinzak et al. (2001) reported that female runners exhibited reduced peak knee flexion and less knee flexion excursion compared to men. The results of the present investigation are in contrast to Malinzak et al. (2001) and Kerrigan et al. (1998) and suggest that sagittal plane hip and knee kinematics and kinetics do not differ between male and female recreational runners.

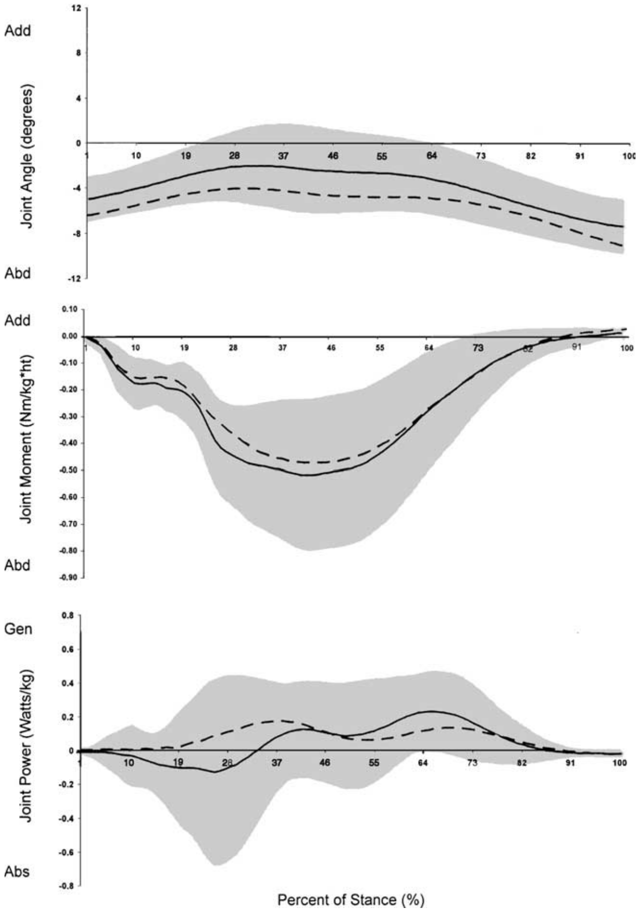

Fig. 5. Knee frontal plane angular motion (top graph) joint moment (middle graph), and power patterns (bottom graph) for men (solid line is mean, shaded area is ±1 SD) and women (dashed line) during the stance phase of running. Positive values indicate knee adduction, adductor moment, and power generation, negative values indicate knee abduction, abductor moment, and power absorption.

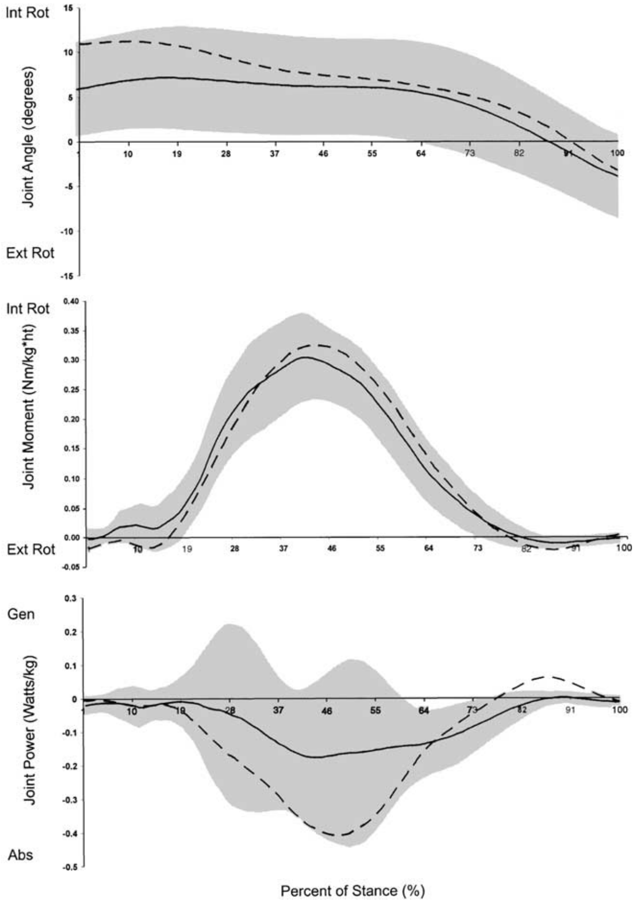

Fig. 6. Hip transverse plane angular motion (top graph), joint moment (middle graph), and power patterns (bottom graph) for men (solid line is mean, shaded area is ±1 SD) and women (dashed line) during the stance phase of running. Positive values indicate hip rotation, internal rotator moment, and power generation, negative values indicate hip external rotation, external rotator moment, and power absorption.

In the frontal plane, females exhibited significantly greater peak hip adduction angle and hip frontal plane negative work while running compared to men. In addition, females demonstrated a greater peak hip adduction velocity but similar peak hip adduction moments compared to men (Fig. 4). While not measured in the current study, Horton and Hall (1989) reported that women exhibit a greater hip width to femoral length ratio. The greater peak hip adduction angle as well as greater hip adduction throughout stance seen in women may be the result of this structural difference (Fig. 4).

The female runners also exhibited significantly more hip frontal plane negative work compared to men (Fig. 4). Since peak joint moments were similar between genders, the greater frontal plane negative work exhibited by the female runners can be attributed to a greater hip adduction angular velocity. These data suggest that as a result of the greater hip adduction angle and velocity, greater eccentric demands were placed in the hip abductors compared to men. Only one other study has reported on differences in hip kinematics and kinetics. Kerrigan et al. (1998) examined only sagittal plane variables and only during walking, but also reported that women exhibited greater amounts of hip motion and negative work during the stance phase of gait.

In partial support of the hypotheses, and in support of Malinzak's findings (2001), females demonstrated a significantly greater peak knee abduction angle and were in a more abducted knee position throughout stance compared to males (Fig. 5). It is possible that the greater hip adduction position contributed to the greater knee abduction angle. Benas (1984) reported that women have a greater amount of genu valgum at the knee, which may have also contributed to the greater peak angle values observed in the present study. In addition, the female runners were in greater amounts of knee abduction at heel strike and remained in greater abduction throughout stance compared to men (Fig. 5).

In the transverse plane, peak hip internal rotation occurred at heel strike followed by external rotation

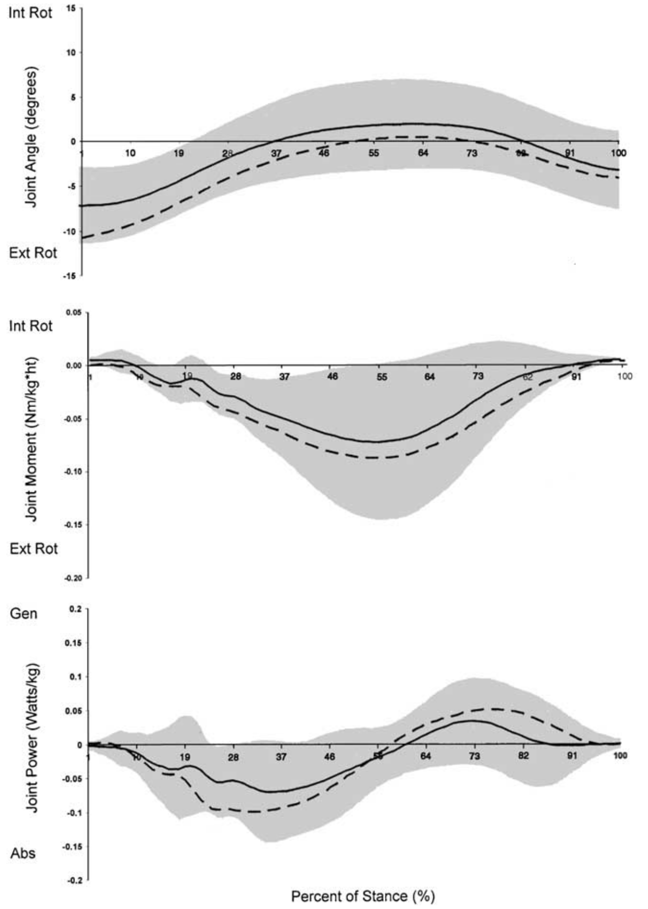

Fig. 7. Knee transverse plane angular motion (top graph), joint moment (middle graph), and power patterns (bottom graph) for men (solid line is mean, shaded area is ±1 SD) and women (dashed line) during the stance phase of running. Positive values indicate knee internal rotation internal rotator moment, and power generation, negative values indicate knee external rotation, external rotator moment, and power absorption.

throughout the remainder of stance (Fig. 6). The female runners exhibited greater hip internal rotation at heel strike resulting in greater external rotation excursion and velocity compared to male runners (Fig. 6). This greater transverse plane motion may have led to a greater transverse plane eccentric work compared to the male runners (Fig. 6). It would be interesting to note whether these dynamic findings were correlated to greater active hip internal rotation range of motion as seen by Simoneau et al. (1998).

The increased hip internal rotation angle observed in the female runners (Fig. 6) likely led to the reduced peak external knee rotation angle compared to men (Fig. 7). In addition, the female runners remained in greater amounts of tibial external rotation compared to men throughout the entire stance phase of gait (Fig. 7). These results are in support of Yoshioka et al. (1989) who reported that women exhibit greater static external knee rotation alignment compared to men. Tiberio (1987) suggested that excessive internal rotation of the femur may result in malalignment of the patellofemoral joint and lead to anterior knee pain. The increased hip internal rotation observed by females in the present study coupled with the greater knee abduction (valgum) may result in a greater dynamic Q-angle. An increase in the Q-angle is thought to result in higher patellofemoral joint contact forces and place a runner at greater risk for injury (Cowan et al., 1996; Mizuno et al., 2001). These results may also partially explain why female runners are twice as likely to develop patellofemoral dysfunction (Almeida et al., 1999; DeHaven and Lintner, 1986).

Structural measurements (i.e. genu valgum, Q-angle, hip rotation) were not recorded for the subjects involved in this investigation. Therefore, direct associations between structure and mechanics cannot be made. In addition, the subjects involved were part of a normative database and were injury free at the time of testing. Thus, relationships between gait patterns and injury cannot be established. This is the first study to examine gender differences in the sagittal, frontal, and transverse planes of motion at the hip and knee during running. However, prospective studies measuring structural characteristics, gait mechanics, and subsequent injuries between genders are needed to further the understanding between structure, mechanics, and injuries.

Additional limitations and delimitations in this study are recognized. The participants in the present investigation all ran within a running speed range of 3.65 m/s (±5%) and the women were on average 14 cm shorter in height than the males. At a fixed running speed, a shorter subject would have to run with a higher cadence and would experience shorter stance duration as compared to taller subjects. However, no differences in stance duration were observed between the male and female runners and, thus, the small difference in group heights may not have significantly influenced running cadence and thus the results of the present investigation. In addition, the running speed range chosen was a comfortable pace for all the subjects and was similar to their own regular training pace. The anthropometric model used to calculate the kinetic variables of interest was not specific to female subjects. Using a model that accounts for the true mass segment properties of females may influence the results of the study. However, since the data were normalized to subject mass and height, this limitation was reduced but it is acknowledged that future studies using an anthropometric model specific to female subjects may provide slightly different results.

In conclusion, female recreational runners exhibited significantly different hip and knee kinematic and kinetic gait patterns compared to men. These results suggest that care should be taken to account for gender when studying groups of male and female recreational runners. In addition, further studies are needed to examine whether these differences in joint mechanics are related

Table 1

Comparisons (mean (SD)) of knee and hip peak joint angle, negative work, peak angular velocity, and peak joint moments

Variable of interest	Male	Female	*P* value
Peak angle (deg)			
Hip flexion	33.29 (6.21)	34.81 (7.00)	0.79
Knee flexion	−45.02 (3.54)	−46.00 (4.23)	0.66
Hip adduction	5.59 (4.67)	9.19 (6.64)	0.05*
Knee abduction	−4.58 (2.51)	−6.44 (2.06)	0.04*
Hip int. rotation	7.02 (5.11)	11.17 (4.92)	0.01*
Knee int. rotation	2.71 (4.66)	0.79 (5.14)	0.25
Negative work (J)			
Hip sagittal plane	−0.95 (0.63)	−1.26 (0.63)	0.51
Knee sagittal plane	−3.64 (1.02)	−3.38 (0.98)	0.71
Hip frontal plane	−0.47 (0.27)	−0.71 (0.30)	0.01*
Knee frontal plane	−0.17 (0.13)	−0.18 (0.18)	0.73
Hip trans. plane	−0.13 (0.08)	−0.29 (0.18)	0.01*
Knee trans. plane	−0.06 (0.04)	−0.08 (0.07)	0.24
Peak angular velocity (deg/s)			
Hip flexion	103.53 (27.09)	129.02 (38.48)	NA
Knee flexion	−506.46 (75.77)	−509.03 (58.18)	NA
Hip adduction	70.00 (41.96)	107.11 (46.26)	NA
Knee abduction	96.96 (38.79)	95.41 (35.61)	NA
Hip int. rotation	−153.65 (49.02)	−193.08 (54.73)	NA
Knee int. rotation	142.84 (51.47)	174.82 (63.64)	NA
*Peak joint moment (Nm/(kg*ht))*			
Hip extension	−1.53 (0.29)	−1.73 (0.24)	NA
Knee extension	1.31 (0.21)	1.14 (0.23)	NA
Hip adduction	−1.24 (0.17)	−1.34 (0.20)	NA
Knee abduction	−0.51 (0.22)	−0.47 (0.18)	NA
Hip int. rotation	0.30 (0.06)	0.33 (0.11)	NA
Knee ext. rotation	−0.02 (0.05)	−0.03 (0.06)	NA

Note: * indicates females significantly greater than males ($P < 0.05$).

to the differences in injury patterns in male and female recreational runners.

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