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Gender Differences in the Kinetics and Kinematics of Distance Running: Implications for Footwear Design

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Abstract. Interest in distance running amongst females has expanded rapidly. Although there are numerous health benefits associated with running, the occurrence of injury is well documented. Given the relative susceptibility of females to overuse running injuries, a key issue within the discipline of footwear biomechanics that has yet to be appropriately addressed is the specific demands of athletic footwear for females. The aim of this study was therefore to provide both a kinetic and 3-D kinematic comparison of male and female runners in order to determine the relative susceptibility of females to the proposed mechanisms of overuse injuries and whether based on this information, females require more specific footwear designs to meet their needs.

Twelve male participants and twelve female participants' completed five successful trials running at 4.0ms^{-1}$\pm$5%. 3-D angular joint kinematics from the hip, knee and ankle were collected using an eight camera motion analysis system. In addition simultaneous tibial acceleration and ground reaction forces were obtained. Differences in impact parameters and joint kinematics were subsequently compared using independent samples t-tests. Females were found to be associated with significantly greater knee abduction, knee internal rotation and ankle eversion, whilst males were associated with significantly greater hip flexion. Based on these findings it is recommended that females select running footwear with design characteristics aimed towards the reduction of coronal plane ankle eversion in order to reduce the incidence of injury.

Keywords: Male, female, kinematics, footwear, impact shock

1. Introduction

Running, is the sport of choice for millions of people, both males and females alike (Taunton *et al.*, 2002). A rapid growth in distance running participation has been witnessed amongst the female population (Nelson *et al.*, 1995; Lilley *et al.*, 2011). This increase in women's running activities has stimulated many sport scientists to investigate the various aspects of female running performance. Although there are numerous health benefits associated with running, the risk of injury is also well documented (Taunton *et al.*, 2002). There are several notable anatomical and physiological differences between males and females that may influence running biomechanics. The average mature male is greater in both height and mass and has a lower body fat percentage (Atwater 1990). In a study providing anatomical reference data Morris *et al.*, (1982) found that males are on average 0.12m taller than females and 18kg heavier, whilst carrying on average 9% less body fat. Increased muscular mass in males is attributable to the higher levels of testosterone, whilst increases in oestrogen contribute to the higher body fat percentage found in females (Morris *et al.*, 1982).

It has been postulated that differences in structure may predispose females to variations in running mechanics which, over many repetitions, may cause females to sustain different injury characteristics than age matched males. Evidence suggests that females are almost twice as likely to sustain a running related injury such as patellofemoral pain syndrome, stress fractures, iliotibial band syndrome or gluteus medius injury (Geraci and Brown, 2005; Taunton *et al.*, 2002), yet the gender specific aetiology of these injuries are not fully understood (Taunton *et al.*, 2002). Gender differences in kinetics and lower extremity kinematics during running have been suggested as a contributing factor (Ferber *et al.*, 2003; Schache *et al.*, 2003) and whilst gender differences in lower extremity structure have been studied, little attention has been devoted to differences in running mechanics between genders.

Only a small number of investigations to date have investigated differences in lower extremity joint mechanics between genders during running. Malinzak *et al*., (2001) investigated gender differences in coronal and sagittal plane knee motion. It was demonstrated that the whilst the coronal plane knee excursion was similar between genders, women were found to exhibit less peak knee flexion and a lower range of motion in the knee compared to men. Ferber *et al*., (2003) examined the gender differences in 3-D kinematics of the hip and knee. Female runners exhibited greater peak hip adduction, hip internal rotation and knee abduction compared to men. Whilst informative, these studies did not investigate ankle kinematics or observe the kinetic loading parameters between genders. There has yet to be an investigation which has examined both the kinetics and 3-D kinematics of the lower extremities of male and female runners.

The running shoe acts as the primary interface between the runner and the road, and thus has an important role to play in the management of injuries. A key concern is the demands of specific running footwear for females when compared to men's shoes. Given the relative susceptibility of females to overuse running injuries, a key issue within the discipline of footwear biomechanics that has yet to be addressed is the specific demands of athletic footwear for females. Footwear manufacturers frequently produce footwear for females on the basis of data collected using male participants. This has led to women's running shoes being habitually designed using a scaled down version of a man's shoe with all dimensions reduced proportionally according to the length of the foot (Wunderlich and Cavanagh 2002). Thus, it is possible that there is a paucity of footwear models that meet the specific needs of female runners both in terms of protection from injury and appropriate fit. As participation in distance running amongst females has increased, new information regarding the biomechanical aspects of female distance running mechanics would be of both theoretical and practical significance. A greater understanding of the differences in running mechanics between male and female runners may also provide an insight into the aetiology of different injury patterns and how these injuries may be attenuated using appropriate footwear designs.

The present study aimed to provide both a kinetic and 3-D kinematic comparison of male and female runners in order to determine 1) the relative susceptibility of females to the proposed mechanisms of overuse injuries and 2) whether females require more specific footwear designs to meet their needs. This examination presents information that may aid footwear manufacturers regarding the design of future shoe models for female runners.

2. Methods

2.1. Participants

Twelve male participants and twelve female participants volunteered to take part in this investigation. All were injury free at the time of data collection and provided written informed consent. Participants were active recreational runners who completed 25km across a minimum of 3 training sessions per week. The mean characteristics of the participants were males; age 25.08 $\pm$ 5.30 years, height 1.78 $\pm$ 0.04 m and mass 71.33 $\pm$ 5.38 kg and females; age 25.04 $\pm$ 4.87 years, height 1.68 $\pm$ 0.04 m and mass 62.67 $\pm$ 3.75 kg. A statistical power analysis was conducted in order to reduce the likelihood of a type II error and determine the minimum number of participants needed for this investigation. It was found that the sample size was sufficient to provide more than 80% statistical power. The procedure was approved by the University of Central Lancashire (School of Psychology) ethics committee.

2.2. Procedure

Participants ran at 4.0ms^{-1} over a piezoelectric force plate (Kistler, Kistler Instruments Ltd., Alton, Hampshire) embedded in the floor (Altrosports 6mm, Altro Ltd,) of a biomechanics laboratory. Running velocity was quantified using infrared timing gates Newtest 300 (Newtest, Oy Koulukatu, Finland), a maximum deviation of $\pm$5% from the set velocity was allowed. Participants completed a minimum of five successful trials. Stance time during contact with the force plate was determined as the time over which 20N or greater of vertical force was recorded. A successful trial was defined as one within the specified velocity range, where all tracking clusters were in view of the cameras, the foot made full contact with the force plate and with no evidence of gait modification due to the experimental conditions.

Kinematics and tibial acceleration data were also synchronously collected. Kinematic data was captured at 250 Hz via an eight camera motion analysis system (Qualisys Medical AB, Goteburg, Sweden). Calibration of the system was performed before each data collection session. Only calibrations which produced average residuals of less than 0.85 mm for each camera for a 750.5mm wand length and points above 4000 in all cameras were accepted prior to data collection.

The marker set used for the study was based on the CAST technique (Cappozo *et al*., (1995). Retro-reflective markers were attached to the 1st and 5th metatarsal heads, calcaneus, medial and lateral malleoli, medial and lateral epicondyle of the femur, greater trochanter of the right leg, iliac crest, anterior superior iliac spines and posterior superior iliac spines with tracking clusters positioned on the shank and thigh. Each rigid cluster comprised four 19mm diameter spherical reflective markers mounted to a thin sheath of lightweight carbon fibre with length to width ratios in accordance with (Cappozzo *et al*., 1997). A static trial was conducted with the participant in the anatomical position in order for the positions of the anatomical markers to be referenced in relation to the tracking clusters, following which they were removed.

A tri-axial (Biometrics ACL 300, Gwent United Kingdom) accelerometer sampling at 1000Hz was used to measure axial accelerations at the tibia. The device was mounted on a piece of lightweight carbon-fibre material using the protocol outlined by Sinclair *et al*., (2010). The combined weight of the accelerometer and mounting instrument was 9g. The voltage sensitivity of the signal was set to 100mV/g, allowing adequate sensitivity with a measurement range of $\pm$ 100 g. The device was attached securely to the distal anterio-medial aspect of the tibia 8 cm above the medial malleolus in alignment with its longitudinal axis. This location was selected to attenuate the influence ankle rotation can have on the acceleration magnitude (Lafortune & Hennig, 1991). Strong adhesive tape was placed over the device and the lower leg to avoid overestimating the acceleration due to tissue artefact. The device was positioned as close to the underlying tibia as possible and the skin overlying the bone itself was stretched ensuring a more rigid coupling between accelerometer and tibia.

2.3. Data Processing

Trials were processed in Qualisys Track Manager in order to identify anatomical and tracking markers then exported as C3D files. Kinematic parameters were quantified using Visual 3-D (C-Motion Inc., Gaithersburg, USA) following the smoothing of marker data using a low-pass Butterworth 4th order zero-lag filter at a cut off frequency of 10Hz. This frequency was selected as being the frequency at which 95% of the signal power was below. 3-D kinematics of the hip knee and ankle joints were calculated using an XYZ cardan sequence of rotations (where X is flexion-extension; Y is ab-adduction and is Z is internal-external rotation). All data were normalized to 100% of the stance phase then processed gait trials were averaged. 3-D kinematic measures from the hip, knee and ankle which were extracted for statistical analysis were 1) angle at footstrike, 2) angle at toe-off, 3) range of motion during stance, 4) peak angle during stance and 5) relative range of motion from footstrike to peak angle.

The accelerometer signal was filtered using a 60Hz Butterworth zero-lag 4th order low pass filter to prevent any resonance effects. Peak positive axial tibial acceleration was defined as the highest positive acceleration peak measured during the stance phase. To analyze data in the frequency domain, a fast fourier transformation function was performed and median power frequency content of the acceleration signals were calculated. Forces were reported in bodyweights (BWs) to allow normalisation of the data between participants. From the force plate data, peak braking and propulsive forces, stance time, average loading rate, instantaneous loading rate, peak impact force and time to peak impact were calculated. Average loading rate was calculated by dividing the impact peak magnitude by the time to the impact peak. Instantaneous loading rate was quantified as the maximum increase in vertical force between frequency intervals.

2.4. Shoes

The shoes utilized during this study consisted of a Saucony Pro Grid Guide 2; they differed in size only (sizes 6, 7 and 9 in men’s shoe UK sizes).

2.5. Statistical Analysis

Descriptive statistics including means and standard deviations were calculated for each footwear condition. Differences in 3-D kinematic parameters, impact shock and impact forces were examined using independent samples t-tests with significance accepted at the $p \leq 0.05$ level. All statistical procedures were conducted using SPSS 19.0. The Shapiro-Wilk statistic for each footwear condition confirmed that the normal distribution assumption was met for the data set.

3. Results

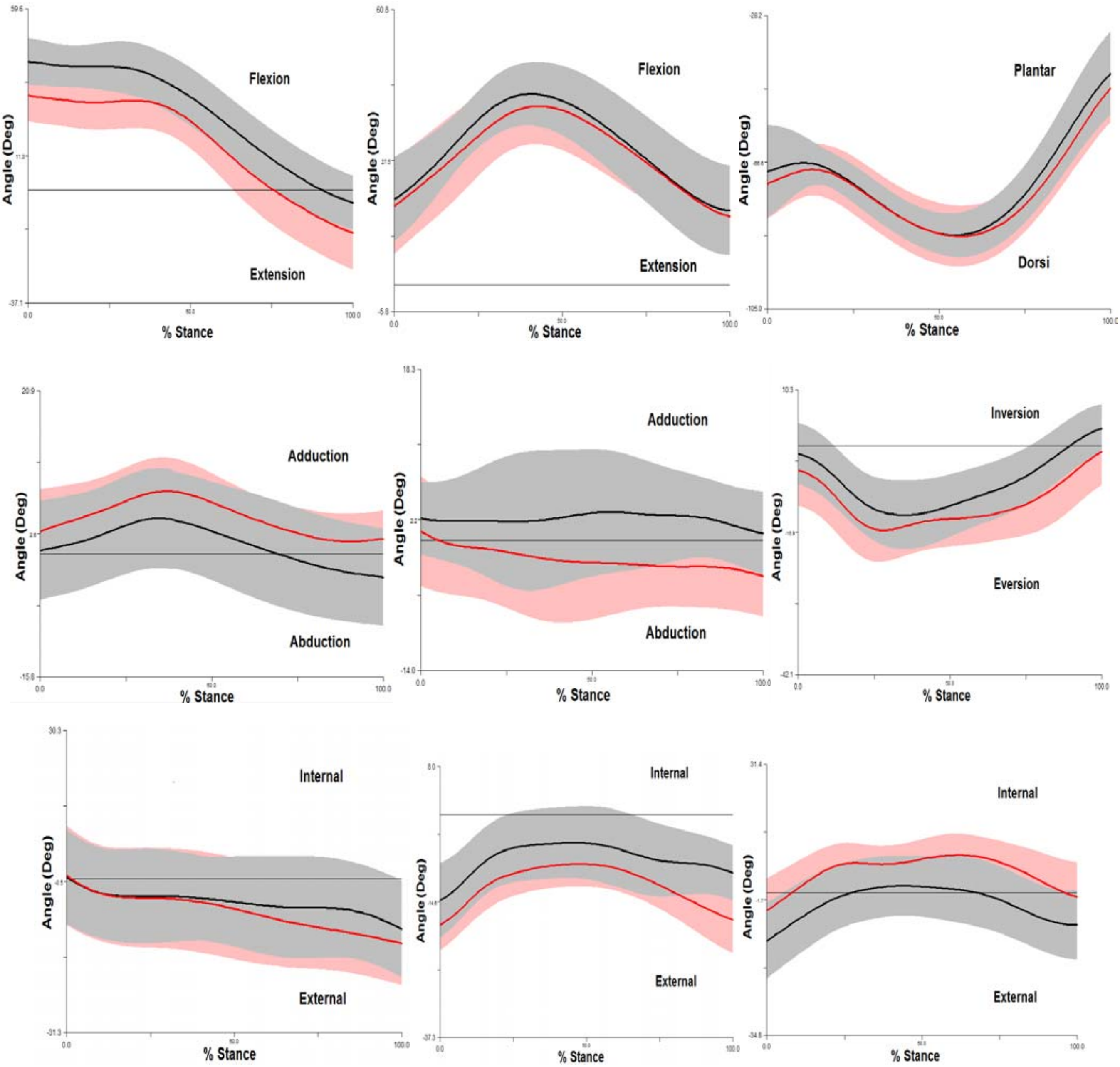

Figure 1: Mean and standard deviation hip, knee and ankle joint kinematics in the a. sagittal, b. coronal and c. transverse planes for males (black line) and females (red line), running (shaded area is 1 $\pm$SD).

In the sagittal plane the results indicate that the males exhibited significantly t (22) = 3.22, $p \leq 0.01$ more hip flexion at initial contact than the female group. Furthermore, it was also found that peak hip flexion was significantly t (22) = 3.64, $p \leq 0.01$ greater in the male group. Finally, the results indicate that the hip was significantly t (22) = 2.21, $p \leq 0.05$ more flexed at toe-off in the male group. In the coronal plane a significant difference t (22) = 2.09, $p \leq 0.05$ between genders was found at toe-off. The male group was found to exhibit abduction whilst the female group exhibited adduction.

Table 1: Kinetic and temporal variables (means, standard deviations) as a function of gender (* = Significant main effect p≤0.05).

	Male	Female	
Vertical Impact Peak (BW)	1.81 ± 0.51	1.91 ± 0.30	
Instantaneous Loading Rate (BW.s^{-1})	157.27 ± 59.61	155.27 ± 59.99	
Average Loading Rate (BW.s^{-1})	68.43 ± 14.41	76.51 ± 29.21	
Time to Peak Impact (s)	0.028 ± 0.006	0.027 ± 0.006	
Peak Braking Force (BW)	0.51 ± 0.14	0.45 ± 0.08	
Peak Propulsive Force (BW)	0.38 ± 0.05	0.38 ± 0.05	
Peak Medial Force (BW)	0.13 ± 0.08	0.12 ± 0.08	
Peak Lateral Force (BW)	0.19 ± 0.03	0.19 ± 0.10	
Peak Axial impact shock (g)	5.13 ± 2.67	6.51 ± 2.85	
Median Power Frequency (Hz)	14.03 ± 12.07	13.29 ± 8.33	
Stance time (ms)	210.6 ± 32	203.9 ± 29	

The results indicate that no significant p>0.05 differences in kinetic or temporal variables exist between male and female runners.

Table 2: Hip kinematics (means, standard deviations) from the stance limb as a function of gender (* = Significant main effect p≤0.05).

	Male	Female	
Hip			
X (+=flexion/-=extension)			
Angle at Footstrike (Deg)	43.23 ± 5.94	32.48 ± 9.93	*
Angle at Toe-off (Deg)	-3.63 ± 8.73	-13.26 ± 12.32	*
Range of Motion (Deg)	46.86 ± 7.52	45.61 ± 6.97	
Peak Range of Motion (Deg)	2.31 ± 2.86	1.26 ± 1.99	
Peak Flexion (Deg)	45.53 ± 6.21	33.61 ± 9.49	*
Y (+=adduction - =abduction)			
Angle at Footstrike (Deg)	1.28 ± 6.50	3.20 ± 4.63	
Angle at Toe-off (Deg)	-2.25 ± 6.37	2.20 ± 3.76	*
Range of Motion (Deg)	3.81 ± 2.32	4.15 ± 3.26	
Peak Range of Motion (Deg)	4.53 ± 3.15	5.72 ± 2.27	
Peak Adduction (Deg)	6.81 ± 6.41	10.93 ± 3.20	
Z (+=internal/- =external)			
Angle at Footstrike (Deg)	2.16 ± 9.33	2.00 ± 9.69	
Angle at Toe-off (Deg)	-12.40 ± 8.54	-8.98 ± 10.16	
Peak external Rotation (Deg)	-13.33 ± 8.51	-10.21 ± 9.42	
Peak Range of Motion (Deg)	15.41 ± 5.48	12.36 ± 5.77	
Range of Motion (Deg)	11.21 ± 6.27	14.81 ± 6.16	

Table 3: Knee kinematic (means, standard deviations) from the stance limb as a function of gender (* = Significant main effect p≤0.05).

	Male	Female	
Knee			
X (+=flexion/-=extension)			
Angle at Footstrike (Deg)	19.84 ± 8.60	19.20 ± 10.50	
Angle at Toe-off (Deg)	17.43 ± 8.83	16.20 ± 8.34	
Range of Motion (Deg)	8.99 ± 4.58	7.95 ± 5.16	
Peak Range of Motion (Deg)	23.96 ± 9.77	21.95 ± 4.83	
Peak Flexion (Deg)	43.80 ± 7.18	41.15 ± 7.51	
Y (+=adduction - =abduction)			
Angle at Footstrike (Deg)	2.35 ± 3.60	1.64 ± 5.53	
Angle at Toe-off (Deg)	0.42 ± 3.87	-3.77 ± 4.63	*
Range of Motion (Deg)	3.19 ± 2.87	6.42 ± 5.27	
Peak Range of Motion (Deg)	3.73 ± 3.58	6.99 ± 5.18	
Peak Angle (Deg)	6.08 ± 5.91	-5.35 ± 4.68	*
Z (+=internal/- =external)			
Angle at Footstrike (Deg)	-13.53 ± 9.03	-4.89 ± 6.62	*
Angle at Toe-off (Deg)	-9.06 ± 8.73	-0.05 ± 7.34	*
Range of Motion (Deg)	6.39 ± 5.82	7.29 ± 4.88	
Peak Range of Motion (Deg)	15.70 ± 5.47	15.83 ± 4.43	
Peak Internal Rotation (Deg)	2.17 ± 7.59	10.94 ± 5.04	*

In the coronal plane a significant difference t (22) = 5.25, p≤0.01 between genders was observed for the magnitude of peak coronal plane knee rotation. The male group exhibited adduction whilst the female group were found to exhibit abduction. Furthermore, a significant t (22) = 2.41, p≤0.05 difference between males and females was observed at toe-off, once again females were found to exhibit abduction whilst males exhibited adduction. In the transverse plane male runners were found to be associated with significantly (22) = 2.67, p≤0.05 more external rotation at footstrike. Furthermore, females were found to be associated with significantly t (22) = 3.33, p≤0.01 greater peak internal rotation magnitude whilst it was also observed that male runners exhibited significantly t (22) = 2.74, p≤0.05 more external rotation at toe-off.

In the coronal plane female runners were found to be associated with a significantly t (22) = 2.21, p<0.05 greater magnitude of peak eversion. In addition a significant difference t (22) = 2.36, p<0.05 between genders was observed at toe-off, with male runners exhibiting inversion and female runners exhibiting eversion. Furthermore, in the transverse plane a significant difference t (22) = 4.60, p<0.01 between genders was observed at toe-off, with females exhibiting more external rotation.

Table 4: Ankle kinematics (means, standard deviations) from the stance limb as a function of gender (* = Significant main effect p≤0.05).

	Male	**Female**	
Ankle			
X (+ =plantar/- =dorsi)			
Angle at Footstrike (Deg)	-70. 35 ± 11.34	-71.77 ± 9.27	
Angle at Toe-off (Deg)	-43.12 ± 8.21	-48.07 ± 8.75	
Range of Motion (Deg)	28.51 ± 11.48	23.70 ± 10.80	
Peak Range of Motion (Deg)	15.97 ± 9.74	15.94 ± 7.24	
Peak Dorsi-Flexion (Deg)	-86.27 ± 5.75	-87.26 ± 7.18	
Y (+=inversion/ - =eversion)			
Angle at Footstrike (Deg)	-1.97 ± 5.25	-5.39 ± 7.34	
Angle at Toe-off (Deg)	3.15 ± 3.26	-1.94 ± 6.74	*
Range of Motion (Deg)	6.28 ± 3.17	5.17 ± 3.30	
Peak Range of Motion (Deg)	11.82 ± 3.15	12.12 ± 3.88	
Peak Eversion (Deg)	-11.97 ± 4.23	-17.51 ± 7.57	*
Z (+=internal/- =external)			
Angle at Footstrike (Deg)	-14.27 ± 5.93	-18.18 ± 3.82	
Angle at Toe-off (Deg)	-10.00 ± 3.36	-17.68 ± 4.70	*
Range of Motion (Deg)	5.31 ± 2.84	4.55 ± 3.09	
Peak Range of Motion (Deg)	10.47 ± 3.10	10.66 ± 3.87	
Peak Angle (Deg)	-4.00 ± 4.52	-17.51 ± 7.66	

4. Discussion

The purpose of this investigation was to determine if female runners have different biomechanical characteristics than male runners and to use this information to provide recommendations for appropriate footwear design.

Few investigations have been devoted to the differences in impact kinetics between male and females during running. The results of this study identified no significant kinetic differences in impact parameters between genders. The results of the current investigation appear to support the findings of both Decker *et al.*, (2003) and Ryu (2005) who reported no gender differences in either time or frequency domain impact parameters. However, they appear to oppose the findings of Heinng (2001) and Stefanyshyn *et al.*, (2003) who found that at matched velocities females were associated with significantly greater loading rates than males, although neither of these investigations examined gender differences in the frequency domain. Thus, it is concluded that gender differences in lower extremity running injuries do not appear to be related to variations in impact parameters. Therefore, with regards to the selection of appropriate footwear designs, it appears based on the findings of the current investigation with respect to shock attenuation; females do not require different footwear properties than males. This opposes the conclusions of Stefanyshyn *et al.*, (2003) who suggested that females require footwear with additional shock attenuating properties. In addition Stefanyshyn *et al.*, (2003) documented that in subjective ratings of heel cushioning females indicated that they would prefer more cushioning in the heel region. As such it may be that females perceive the cushioning properties of footwear differently which serves to influence their selection of running footwear. This is something that is difficult to quantify accurately due to its subjectivity, but nonetheless should be investigated further.

It is also emerging within biomechanical literature that females are at considerably greater risk of developing stress fractures, having up to four times the frequency when compared to age matched males (Pester and Smith, 1992). A relationship between increased vertical impact loading and the incidence of stress fractures (particularly at the tibia) has emerged within the epidemiological literature. In a number of retrospective studies, runners with a history of stress fractures have exhibited a higher tibial shock and vertical ground reaction force parameters than healthy controls (Grimston *et al*., 1991; Hreljac *et al*., 2000 and Ferber *et al*., 2002). The results of the current investigation appear to provide only partial support for this conjecture; although a number of impact parameters were found to be higher in the female runners none were sufficiently greater to reach statistical significance. Bone exhibits both cellular and molecular remodelling responses to the mechanical stresses experienced during gait. This remodelling occurs throughout life and is affected by multiple factors. Therefore, it appears that the aetiology of stress fractures is complex and extends beyond increases in impact loading. Therefore, other factors such as bone structure, thigh and calf musculature, fitness level, body fat and hormonal variations, may also be significant (Hoch *et al.,* 2005). Whilst these factors are beyond the scope of this investigation, future investigations examining how these factors influence the aetiology of stress fractures may assist in developing strategies to reduce the occurrence of such injuries.

Significant differences in 3-D kinematic parameters were observed between genders. With respect to sagittal plane motion of the hip, males were found to be associated with increased hip flexion throughout the stance phase. This evidence opposes the findings of Ferber *et al*., (2003), Schache *et al*., (2003) and Chumanov *et al*., (2008) who observed no gender differences in sagittal plane hip motion. It is difficult to elucidate to mechanisms behind this difference, however the experimental conditions in the aforementioned investigations differed from the current study. Schache *et al.*, (2003) used a treadmill protocol in order to investigate gender differences in 3-D kinematics. Treadmill locomotion has been associated with different movement strategies in comparison to overground (Chockalingam *et al*., 2006) which may serve to attenuate the differences between genders as it is not yet known to what extent male and female runners accommodate to treadmill running. Furthermore, none of the above investigations controlled for footwear amongst participants. This could potentially account for some of the differences between studies as footwear has been shown to have a significant influence of the kinematics of running (Hardin *et al.,* 2004). It is further hypothesized that this finding relates to the greater absolute stride lengths commonly associated with male runners (Atwater, 1990). Previous investigations Hoffman (1971 and 1972) found moderate to strong correlations between absolute stride length and height in runners. Therefore, given that the male group were almost 10cm taller in the current investigation and as such would be expected to be associated with an increased stride length it is likely that increases in hip flexion associated with male runners are necessary to facilitate the increase in stride length.

With respect to the knee joint complex, no significant differences were observed in the sagittal plane. Previous investigations have reported conflicting results with respect to sagittal plane knee kinematics; Maliznak *et al*., (2001) found that females exhibit less peak knee flexion and less knee flexion excursion in comparison to males, whilst Ferber *et al*., (2003) reported no gender differences in sagittal plane knee kinematics. Hewett *et al*., (2005) propose that females limit the amount of knee flexion during dynamic tasks, and instead, rely more on their passive restraints in the frontal plane (i.e. ligaments) to control these tasks. The results of the current investigation provide partial support for this notion in that females were associated with non-significant reductions in knee flexion and significant increases in frontal plane knee abduction. It has been hypothesized that females lack the strength and/or neuromuscular control of the sagittal plane musculature to effectively decelerate the body centre of mass during landing and thus rely on frontal plane mechanics to a greater extent than males. Hewett *et al*., (2005) found that both knee valgus motion and moments to be predictors of ACL injury. In general, the knee joint mechanics exhibited by females are thought to place them at a greater risk of ACL injury. Therefore, it appears that females are at greater risk from non-contact ACL injuries. The results of this study provide basis for future work examining the underlying mechanisms behind this movement strategy and geometric differences in the size and shape of the ACL and their influence on the aetiology of non-contact ACL injuries.

In the coronal plane females were found to be associated with significantly greater peak knee abduction and knee abduction at toe-off. This concurs with the findings of Cho *et al*., (2004), Ferber *et al*., (2003) and Hurd *et al*., (2004) who reported that females were associated with significant increases in knee abduction in comparison to male runners. The greater knee abduction in conjunction with increases (non-significant) in hip adduction associated with female runners may facilitate an increase in dynamic Q-angle. This supports the current conjecture with respect to gender differences in Q-angle (Aglietti *et al*., 1983; Horton and Hall, 1989; Hsu *et al*., 1990). Increases in dynamic Q-angle magnitude enhances the lateral pull of the quadriceps on the patella (Horton and Hall 1989), which serves to facilitate misalignment of the patellofemoral joint and produces compression of the lateral articular surface and is hypothesized to be associated with greater lateral patellar contact forces and may facilitate a greater incidence of patellofemoral disorders (Mizuno *et al*., 2001). As such, the results of the current investigation appear to at least partially explain the mechanisms behind the increases susceptibility of female runners to patellofemoral disorders and pain (Almeida *et al*., 1999 and DeHaven and Lintner, 1986).

With respect to the ankle joint complex, significant increases in ankle eversion and associated knee internal rotation parameters were reported for the female group. These results concur with the findings of Hennig (2001) and Kernozek *et al.,* (2005) who also observed increases in ankle eversion in female runners. The significant increases in peak eversion and knee internal rotation in female runners also has potential clinical significance. These findings suggest that female runners may be associated with an increased risk from stability related injury as excessive rearfoot eversion and associated knee internal rotation are implicated in the aetiology of a number of overuse injuries such as tibial stress syndrome, plantar fasciitis, patellofemoral syndrome and illiotibial band syndrome (Viitasalo and Kvist, 1983). Significantly, iliotibial band pathology is considered to be the leading cause of lateral knee pain in runners (Taunton *et al*., 2002). Female runners are reported to be twice as likely to suffer from illiotibial band syndrome as males (Taunton *et al*., 2002). The increase in coronal plane eversion in the female condition serves to augment tension in the illiotibial band which is hypothesized by Noehren *et al*., (2006) as a being the mechanism by which illiotibial pathology occurs. As such this finding appears to explain the increased susceptibility of females to illiotibial band injury. Therefore, given the significant increase in rearfoot eversion observed in female runners it is recommended that females select running footwear with design characteristics aimed towards the reduction of calcaneal eversion. It is hypothesized based on the findings of the current investigations that this will serve to reduce the incidence of pathology in female runners.

In conclusion this study provides data not previously available comparing the impact kinetics and lower extremity 3-D kinematics of male and female runners. The current investigation provides insight into the aetiology of different injury patterns that may be observed between genders. Furthermore, this study supports the notion that females are more susceptible to overuse injuries than males, although further studies are required in order to determine whether gender differences in lower extremity kinematics are related to the incidence of injury. With regards to appropriate footwear, it appears based on the findings of the current investigation with respect to shock attenuation; females do not require different footwear properties than males. However, it is recommended that females select running footwear with design characteristics aimed towards the reduction of coronal plane ankle eversion in order to reduce the incidence of injury. Future research should focus on prospective studies whereby aetiological measures are determined before individuals obtain the injury and as such causative factors may be more accurately determined allowing footwear designs to be developed and prescribed more effectively.

5. Conflict of Interest Statement

No conflict of interest.

6. Acknowledgements

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