Title: The effects of opposition on knee kinematics and ground reaction force during landing from volleyball block jumps.

Abstract

The aim of the study was to examine the effect of opposition on knee kinematics and ground reaction force during landing from a volleyball block jump. Six female and six male university volleyball players performed two landing tasks 1) an unopposed and 2) an opposed volleyball block jump and landing. Knee kinematics were recorded by a 12 camera motion analysis system (120 Hz) and ground reaction force was recorded by a force platform (600 Hz) during landing. The results showed a significant effect for level of opposition in peak normalized GRF, knee flexion at ground contact, maximum knee flexion and range of motion of knee flexion. There was a significant effect for gender in maximum knee flexion, range of motion of knee flexion, maximum knee valgus angle and range of motion of knee valgus. The changes in landing biomechanics as a result of opposition suggest future research investigating landing mechanics should examine opposed exercises since opposition may significantly alter neuromuscular responses.

Key words: Biomechanics, gender differences, ACL injury.

Introduction.

Research suggests that approximately 70% of anterior cruciate ligament (ACL) injuries occur in sporting activities (Faegin, 1988; Johnson, 1988; Smith, Livesay, & Woo, 1988). Studies examining the etiology of ACL injuries report that between 70% and 90% of injuries occur in non-contact situations (Griffin et al., 2000; McNair, Marshall, & Matheston, 1993; Mykelbust, Maehlum, Engbretsen, Strand, & Solheim, 1997). Furthermore, ACL injuries have been reported to occur most frequently during movements such as landing (Hopper & Elliot, 1993), decelerating (Miller, Cooper, & Warner, 1995) or rapidly changing direction (Olsen, Mykelbust, Engebretsen, & Bahr, 2004). The incidence of ACL injuries is therefore high in sports such as basketball, netball, handball and volleyball which involve a high frequency of landing, decelerating and rapid changes of direction (Arendt & Dick, 1995; Griffin et al., 2000). The incidence of non-contact ACL injuries have been reported to be 6 to 8 times greater in females than in males competing in the same sports (Arendt & Dick, 1995; Chandy & Grana, 1985; Ferretti, Papandrea, Conteduca, & Mariani, 1992; Gray et al., 1985; Gwinn, Wilckens, McDevitt, Ross, & Kao, 2000; Lidenfeld, Schmitt, Hendy, Mangine, & Noyes, 1994; Malone, Hardaker, Garrett, Feagin, & Bassett, 1993).

Since ACL injuries have been associated with landing, decelerating and rapidly changing direction, a number of studies which have investigated gender differences the biomechanics associated with these maneuvers (Decker, Torry, Wyland, Sterett, & Steadman, 2003; Ford, Myer, & Hewett, 2003; James, Sizer, Starch, Lockhart, & Slauterbeck, 2004; Kernozek, Torry, Van Hoof, Cowley, & Tanner, 2005; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001; Yu, Lin, & Garrett, 2006). Studies examining sagittal plane kinematics of landing and cutting maneuvers report that females tend to land with less knee flexion angle than males (Decker et al., 2003; James et al., 2004; Malinzak et al., 2001; Yu et al., 2006) and exhibit a greater range of knee flexion than males (Decker et al., 2003). For a given load on the patellar ligament, the more extended the knee, the greater the strain on the ACL is likely to be due to the effect of knee flexion on the patella tendon-tibia shaft angle (Li et al., 1999; Nunley, Wright, Renner, Yu, & Garrett, 2003). A number of observational studies including Boden et al. (2000) and Olsen et al. (2004) have reported that non-contact ACL injuries most frequently occur immediately following initial ground contact with the knee close to full extension. Consequently, since females tend to make contact with the ground with knees in a more extended position than males, the risk of ACL injury may be greater in females relative to males. Studies investigating frontal plane kinematics of landing and cutting report that females tend to exhibit greater maximum knee valgus angle and greater knee valgus angle range of motion compared to males (Ford et al., 2003; Kernozek et al., 2005; Malinzak et al., 2001). Boden et al. (2000) and Olsen et al. (2004) have reported that non-contact ACL injuries appear to occur more frequently when the knee exhibits a valgus movement. Consequently, greater maximum knee valgus angle in females may increase the risk of ACL injury relative to males. Studies examining ground reaction force (GRF) during landing indicate that females tend to exhibit greater normalized peak GRF (Kernozek et al., 2005; Salci, Kentel, Heycan, Akin, & Korkusus, 2004; Yu et al., 2006) than males. The greater the GRF exhibited during landing, the greater the likely load on the passive support structures of the knee.

The demands of the tasks that subjects are required to perform will influence the movement patterns exhibited and therefore influence the validity of comparisons made between males and females. Previous studies examining landing biomechanics in males and females typically use a task involving dropping down from a raised platform set at the same height for both males and females (Decker et al., 2003; Ford et al., 2003; Salci et al., 2004). This may result in significantly different task demands for females compared to males (females are less likely to jump as high as females), particularly in sports such as volleyball where the net is set at a different height for males and females (2.48 m for males and 2.29 m for females). Therefore, a lack of standardization in the task subjects are required to perform in previous studies may have reduced the likelihood of meaningful comparison between males and females. Previous studies have found changes in technique as a result of opposition (Davila, Garcia, Montilla, & Ruiz, 2006). For example, Davila et al. (2006) found significant changes in technique were made by a handball players when shooting during unopposed and opposed conditions. It is reasonable to assume that the attentional demand of jumping and landing in an opposed context will be less than that in an unopposed context (Chen et al., 1996; Lajoie, Teasdale, Bard, & Fleury, 1993) which, in turn, is likely to affect the neuromuscular response when landing. A number of studies have examined gender differences in kinematics and kinetics during landing and cutting maneuvers in unopposed (Decker et al., 2003; Kernozek et al., 2005; Salci et al., 2004; Yu et al., 2006) and opposed (Hughes, Watkins, Owen, & Lewis, 2007) contexts, as well as during game-like situations involving activities such as catching a ball (Cowling & Steele, 2001). However, direct comparison of the results is not possible due to differences in task demands. To our knowledge, no study has examined gender differences in knee kinematics and GRF when performing sport specific landing tasks during both unopposed and opposed conditions. The purpose of the present study was to examine the effect of opposition on knee kinematics and GRF during landing from a volleyball block jump in male and female university volleyball players.

Method.

Subjects.

The subjects were 7 female (Mean age 21.6 ± 1.4 years, mass 58.6 ± 8.2 kg and height 165.6 ± 7.4 cm) and 7 male (Mean age 21.8 ± 4.1 years, mass 71.2 ± 3.0 kg and height 176.7 ± 8.8 cm) university volleyball players. All subjects had no previous history of hip, knee or ankle injury and were right leg dominant. Ethical approval was granted for the study by the University Ethics Committee and written consent forms were signed by all subjects prior to data collection.

Measurement system.

An AMTI force platform sampling at 600 Hz was used to measure the GRF of the right (dominant) leg during landing. A time synchronised 12 camera Vicon 512 system (Vicon, Oxford, England) sampling at 120 Hz was used to determine 3D coordinates of 16 retro-reflective markers (25 mm diameter). Markers were placed directly on the skin over anatomical landmarks in accordance with the Vicon system’s lower body plug-in gait marker set. From the location of the markers placed on the body, combined with required anthropometric measurements of each subject entered into the system, the Vicon system calculated the 3D coordinates of hip, knee and ankle joint centres. The subject anthropometric measurements required were height, weight, leg length, knee width and ankle width. The Vicon system uses the Newington-Gage model to define the positions of the hip joint centres within the pelvis segment (in which pelvis size and leg length are used as scaling factors) in conjunction with the markers placed on the pelvis and leg length measurement to determine the 3D position of hip joint centre (Davis, Ounpuu, Tyburski, & Gage, 1991). The knee joint centre is determined from hip joint centre, knee marker, thigh marker and knee width measurement. The ankle joint centre is determined from the knee joint centre, ankle marker, tibia marker and ankle width measurement. In the plug-in gait system, the measurement of knee flexion angle and valgus/varus angle was determined as the Euler angle of the shank segment reference frame relative to the thigh segment reference plane rotated in the order 1) flexion/extension, 2) valgus/varus, 3) internal/external rotation.

Tasks.

Prior to data collection all subjects performed a 10-min warm up consisting of lower limb stretching and running/jogging on a treadmill at self determined speeds. When this was completed, subjects practiced the jumping and landing tasks until comfortable with the procedure. To carry out the landing task, a rope was fixed horizontally 5 cm in front of the force platform to act as a volleyball net at a height of 2.43 m for male subjects and 2.24 m for female subjects (height of a standard volleyball net). Also, a volleyball was suspended from the ceiling and positioned with the bottom of the ball 5 cm above the net (2.48 m for males and 2.29 m for females) and with the centre of the ball 10 cm in front of the line of the net (the other side of the net to where the subject (blocker) was standing). This was considered to be a typical position from which a volleyball would be spiked from. Subjects were required to perform two landing tasks: unopposed volleyball block jump and landing and opposed volleyball block jump and landing. 1) Unopposed: At the start of each trial, the subject stood with their right foot on the force plate. The subject was then instructed to jump up and pretend to block the suspended volleyball. On landing, the right foot landed on the force plate. 2) Opposed: At the start of each trial, the subject stood with their right foot on the force plate. The subject then timed his/her blocking action in order to try to block the ball as it was spiked. In all trials, the person spiking the volleyball was of a similar playing standard to the blocker. The ball was spiked from the same suspended position in order to eliminate variation in the position and velocity of the ball. On landing, the right foot landed on the force plate. Data were recorded for three successful trials for each landing task for each subject. Trials where the entire right foot alone did not land on the force plate were discarded.

Data analysis.

The 3D coordinate data were filtered using a Woltring Filter. To alter the filter settings a mean squared error (MSE) tolerance value was entered into the Vicon system. The MSE method allows the noise level to be input and a spline function is fitted to the data points in accordance with the specified level of tolerance. Consistent application of this processing method ensured the same level of smoothing for all marker trajectories. Based on a primary consideration of minimising high frequency artefacts whilst maintaining the detail of the signal at all lower frequencies, it was determined that it would be most appropriate to use a MSE value of 50 as a suitable setting for filtering the data. This was determined by analysing the effects of a number of different filter settings for sample data of a number of different jumps and from a number of different subjects. In determining a suitable MSE value, the data were analysed using a Welch periodogram to provide power spectral density (PSD) plots that quantify the magnitude of power in a narrow frequency band. From the PSD plots, the estimated frequency of the start of signal attenuation, 50% of signal attenuation and almost complete signal attenuation could be determined for the MSE value of 50. The filter setting determined to be most appropriate for these data (i.e. MSE = 50) corresponded to a low-pass filter of cut-off frequency 10 Hz and stop-band frequency of 30 Hz.

The GRF and knee angle in the sagittal (flexion/extension) and frontal (valgus/varus) planes were determined between initial ground contact (IC) and, depending on which occurred later in the trial, either maximum knee flexion or maximum knee valgus/varus angle (MAX) in each trial. Angular displacement mean data (IC, MAX and range of motion (ROM)) were based on 36 trials for males and 36 trials for females (6 subjects × 3 trials × 2 legs). GRF data were normalized to body weight (in Newtons) and mean data were based on 18 trials for males (6 subjects × 3 trials × 1 leg) and 18 trials for females (6 subjects × 3 trials × 1 leg). Mixed between-within subjects analysis of variance (SPANOVA) was carried out on the data to examine the effects of the level of opposition and the effects of gender on angular displacement in the sagittal and frontal planes and normalized GRF, where the alpha level was set at $p<0.05$.

Results.

For all variables, there was no significant interaction between the level of opposition (unopposed/opposed) and gender (females/males) ($p > 0.05$). All Figures show variables plotted against normalized time and against absolute mean trial time between IC and MAX. For the unopposed trials, absolute mean trial time was 0.203 s ± 0.068 for males and 0.213 s ± 0.061 for females. For the opposed trials, absolute mean trial time was 0.190 s ± 0.040 for males and 0.194 s ± 0.057 for females. As there was no significant effect for level of opposition (Wilks Lambada = 0.95, $F = 3.18$, $p = 0.08$, partial eta squared = 0.05) or for gender ($F = 1.16$, $p = 0.29$, partial eta squared = 0.02) for contact time, a mean trial time of 0.200 s was used.

In the sagittal plane, in both males and females during both unopposed and opposed trials, subjects tended to contact the ground with a relatively small knee flexion angle which progressively increased between IC and MAX (Table 1 and Figure 1). In the sagittal plane, there was a significant effect for level of opposition for knee flexion at IC (Wilks Lambada = 0.86, F = 9.68, p = 0.003, partial eta squared = 0.14) with greater knee flexion observed at IC during unopposed trials than opposed trials (Table 1). However, there was no significant effect for gender for knee flexion at IC (F = 3.65, p = 0.06, partial eta squared = 0.06). There was a significant effect for level of opposition (Wilks Lambada = 0.77, F = 17.6, p = 0.001, partial eta squared = 0.23) and a significant effect for gender (F = 13.3, p = 0.01, partial eta squared = 0.19) for sagittal plane knee angle at MAX, with females displaying greater knee flexion at MAX than males and greater knee flexion at MAX observed during unopposed than opposed conditions (Table 1). This resulted in a significant effect for level of opposition (Wilks Lambada = 0.86, F = 9.61, p = 0.003, partial eta squared = 0.14) and a significant effect for gender (F = 14.7, p = 0.001, partial eta squared = 0.20) for ROM of knee angle in the sagittal plane, with females displaying greater ROM of knee flexion than males and greater ROM of knee flexion observed during unopposed than opposed conditions (Table 1).

Table 1 about here.

Figure 1 about here.

In the frontal plane, during both unopposed and opposed trials, females tended to contact the ground with the knee in a valgus position (–ve values) which progressively increased between IC and MAX position. In contrast, during both unopposed and opposed trials, males tended to contact the ground with the knee in a valgus position and moved into a varus position (+ve values) at MAX (Table 1 and Figure 2). There was no significant effect for level of opposition (Wilks Lambada = 1.00, $F = 0.001$, $p = 0.97$, partial eta squared = 0.001) and no significant effect for gender ($F = 0.35$, $p = 0.56$, partial eta squared = 0.01) for the knee valgus angle at IC. For MAX knee valgus angle, there was no significant effect for level of opposition (Wilks Lambada = 0.95, $F = 2.80$, $p = 0.10$, partial eta squared = 0.05) but there was a significant effect for gender ($F = 32.3$, $p = 0.001$, partial eta squared = 0.36) with females exhibiting a greater MAX knee valgus angle than males (Table 1). For ROM of knee angle in the frontal plane, there was no significant effect for level of opposition (Wilks Lambada = 0.94, $F = 4.05$, $p = 0.06$, partial eta squared = 0.07) but there was a significant effect for gender ($F = 38.6$, $p = 0.001$, partial eta squared = 0.40) with females displaying a greater ROM of knee valgus angle than males (Table 1).

Figure 2 about here.

With regard to normalized GRF (Figure 3), the overall shapes of the curves were similar for males and females and for unopposed and opposed trials, i.e. increase during approximately the first 40% of the landing phase followed by decrease during approximately the final 60% of landing. For most of the landing period, the normalized GRF was greater for males than females and greater for opposed trials than unopposed trials. The initial peak in normalized GRF occurred earlier during opposed trials than unopposed trials and the maximum normalized GRF during landing occurred later in opposed trials than unopposed trials. There was no significant effect for level of opposition (Wilks Lambada = 0.93, $F = 2.17$, $p = 0.15$, partial eta squared = 0.07) and no significant effect for gender ($F = 0.07$, $p = 0.79$, partial eta squared = 0.02) for normalized GRF at MAX. For peak normalized GRF, there was a significant effect for level of opposition (Wilks Lambada = 0.93, $F = 4.37$, $p = 0.04$, partial eta squared = 0.07) with greater normalized GRF observed during opposed conditions than unopposed conditions (Table 2). However, there was no significant effect for gender (F = 1.43, p = 0.24, partial eta squared = 0.05) for peak normalized GRF.

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Table 2 about here.

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Figure 3 about here.

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Discussion.

The results indicate differences in sagittal plane kinematics between males and females and between unopposed and opposed trials. There was a significant effect for level of opposition in knee flexion at IC, with greater knee flexion at IC exhibited during unopposed conditions than opposed conditions. ACL strain is likely to be increased with reduced knee flexion (Li et al., 1999; Nunley et al., 2003), therefore during unopposed trials subjects may increase knee flexion at IC compared to opposed trials to reduce the likelihood of ACL strain. There was a significant effect for both gender and level of opposition for MAX knee flexion and ROM of knee flexion, with greater knee flexion exhibited by females compared to males and greater knee flexion exhibited during unopposed conditions than opposed conditions. The results of the present study indicate values of maximum knee flexion measured during unopposed trials were nearer to values reported by previous studies where subjects performed unopposed landing than those measured during opposed conditions. For example, mean maximum knee flexion of 88.9^{o} ± 11.4 for males and 78.3^{o} ± 13.4 for females were reported by Kernozek et al. (2005) compared to 67.2^{o} ± 12.9 for males and 78.0^{o} ± 8.1 for females during unopposed trials and 62.1^{o} ± 11.6 for males and 68.2^{o} ± 12.2 for females during opposed trials. The greater knee flexion exhibited during unopposed conditions compared to opposed conditions may be due to subjects consciously increasing their knee flexion during unopposed trials in an attempt to reduce the impact of the GRF during landing and therefore reduce the risk of injury. However, during opposed trials, due to the greater attentional demand, subjects were, perhaps, less able to consciously increase the amount of knee flexion during landing. These results indicate that sagittal plane kinematics changed significantly with the introduction of opposition to the landing task and highlight the need for ecologically valid task demands in studies designed to examine differences in the incidence of injuries between males and females in specific sports.

The results indicate differences in frontal plane kinematics between males and females but not between unopposed and opposed trials. There was no significant effect for the level of opposition or gender in knee valgus at IC. However, there was a significant effect for gender for MAX knee valgus and ROM of knee valgus, with females displaying greater knee valgus angle than males during landing. However, there were no significant effect for level of opposition in knee valgus angle during landing. These results indicate that differences in frontal plane kinematics between males and females during landing were consistent between unopposed and opposed conditions and may indicate increased risk of ACL injury in females compared to males.

The values of maximum knee valgus angle reported in this study are different to previous results but as with the sagittal plane kinematics, the results of the present study indicate values of maximum knee valgus angle measured during unopposed trials were nearer to values reported by previous studies where subjects performed unopposed landing than those measured during opposed conditions. For example, Ford et al. (2004) reported maximum knee valgus (–ve) / varus (+ve) angle values of -14.3° ± 2.0 for males and -20.1° ± 2.5 for females, compared to -2.2° ± 5.3 for males and -13.9° ± 11.3 for females during unopposed trials and -2.9° ± 7.9 for males and -10.4° ± 7.7 for females during opposed trials in this study. There are a number of possible reasons for these differences which include subjects' age and playing standard and the method of measuring the knee valgus angle. In Ford et al. (2004) the subjects used were high school athletes whereas university athletes were used in this study. The valgus angle measured in Ford et al. (2004) was determined from markers placed on the skin over the greater trochanter, lateral epicondyle of the knee and the lateral malleolus of the ankle, whereas in this study, the valgus angle was based on estimated hip, knee and ankle joint centres using the Vicon plug-in gait model.

There was a significant effect for level of opposition in peak normalized GRF with greater normalized GRF exhibited during opposed conditions compared to unopposed conditions. This may be due to the greater MAX knee flexion and ROM of knee flexion during unopposed trials than opposed trials. For most of the landing period, the normalized GRF was greater for males than females. This is contrary to a number of previous studies examining gender differences in normalized GRF during landing (Kernozek et al., 2005; Salci et al., 2004; Yu et al., 2006). The difference in the findings of the present study and previous studies is likely to be due to differences in task demands subjects were required to perform. Typically, previous studies have examined drop-jump landings from the same set height for males and females whereas the present study examined a sport specific volleyball block jump landing, where males and females were more likely to land from a jump height typical of what they are likely to perform during their sport. The initial peak in normalized GRF occurred earlier during opposed trials than unopposed trials and the maximum normalized

GRF during landing occurred later in opposed trials than unopposed trials. This may be due to subjects being less able to consciously reduce the initial peak in GRF just after ground contact through an increase in knee flexion during opposed conditions compared to unopposed conditions. This may be of particular importance since ACL injury has been reported to occur most frequently when the knee is in a relatively extended position just after initial contact with the ground (Boden et al., 2000; Olsen et al., 2004).

In conclusion, differences in sagittal plane knee kinematics and GRF during opposed and unopposed trials suggest that coaches should implement training programs that involve ecologically valid landing maneuvers. Future research into landing kinematics and kinetics should include opposition during the landing task as the effect of opposition may significantly alter subjects' neuromuscular responses during landing, particularly in the sagittal plane. Differences in frontal plane kinematics between males and females however, appear to be consistent in unopposed and opposed conditions. Therefore the results of this study may validate the results of many other studies (Ford et al., 2003; Kernozek et al., 2005; Malinzak et al., 2001) which have investigated gender differences in frontal plane knee kinematics during landing in unopposed conditions.

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Author notes.

There is no financial interest in the research.

Tables.

Table 1. Group mean results for knee flexion/extension and valgus/varus (– valgus; + varus) angles at IC, MAX and ROM for males and females during unopposed and opposed trials (Mean ± standard deviation).

		Males		Females	
		Unopposed (^{o})	Opposed (^{o})	Unopposed (^{o})	Opposed (^{o})
Flexion	IC *	20.3 ± 4.7	19.4 ± 6.4	19.5 ± 6.9	15.1 ± 6.2
	MAX *†	67.2 ± 12.9	62.1 ± 11.6	78.0 ± 8.1	68.2 ± 12.2
	ROM *†	46.9 ± 14.9	42.7 ± 13.9	58.6 ± 7.4	53.1 ± 13.1
Val/var	IC	-2.2 ± 5.3	-2.8 ± 5.9	-2.1 ± 3.4	-1.6 ± 2.8
	MAX$_{VAL}$ †	-2.2 ± 5.3	-2.9 ± 7.9	-13.9 ± 11.3	-10.4 ± 7.7
	MAX$_{VAR}$	1.0 ± 9.6	0.6 ± 9.1	N/A	N/A
	ROM †	3.2 ± 8.0	3.5 ± 9.6	11.8 ± 10.3	8.8 ± 7.8

* : Significant effect between unopposed and opposed trials ($p < 0.05$).

† : Significant effect between males and females ($p < 0.05$).

Table 2. Group mean results for normalized GRF at MAX and peak (Mean ± standard deviation).

		MAX GRF (BW)	**Peak GRF (BW)**
Males	Unopposed	0.752 ± 0.194	1.561 ± 0.663*
	Opposed	0.972 ± 0.415	1.861 ± 0.595*
Females	Unopposed	0.873 ± 0.210	1.457 ± 0.477*
	Opposed	0.894 ± 0.378	1.631 ± 0.427*

*: Significant effect between unopposed and opposed trials.

Figure captions.

Figure 1. Knee flexion (θ_f) between IC and MAX for males and females during unopposed and opposed trials.

Figure 2. Knee valgus/varus (θ_v) between IC and MAX for males and females during unopposed and opposed trials.

Figure 3. Normalized GRF between IC and MAX for males and females during unopposed and opposed trials.