Title: Gender differences in knee kinematics during landing from volleyball block jumps.

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Summary.

The aims of the present study were to investigate the effects of gender on frontal and sagittal plane knee kinematics in university volleyball players when performing opposed block jump landings. 6 female and 6 male university volleyball players performed volleyball block jumps under opposed conditions. Knee flexion/extension and knee valgus/varus angles and angular velocities were determined during landing. Knee flexion at ground contact was significantly smaller in females than males. Maximum knee flexion and range of motion of knee flexion was significantly greater in females. In the frontal plane, there was no significant difference between males and females in knee valgus angle on ground contact, but females displayed significantly greater maximum valgus angle and range of motion than males. There was a significant difference in maximum valgus and range of motion between the dominant and non-dominant legs in females, but not in males. Angular velocity of the knees in both frontal and sagittal planes was significantly greater in females than males in the passive phase of landing, but not in the active phase. The gender differences in lower limb alignments in normal upright standing do not totally account for the gender differences in landing kinematics. The results appear to indicate less dynamic stability of the knee during landing in females compared to males which may be a contributory factor in the reported greater incidence of ACL injury in females.

1. Introduction.

Between 70% and 90% of anterior cruciate ligament (ACL) injuries have been reported to occur in non-contact situations (Griffin et al, 2000; McNair et al, 1993; Mykelbust et al, 1997). A non-contact situation is where there is no direct contact with the knee at the time of injury. Most non-contact ACL injuries appear to occur during landing (Hopper and Elliot, 1993), deceleration (Miller et al, 1995) or rapid change of direction (Olsen et al, 2004). Furthermore, most non-contact ACL injuries appear to occur close to foot strike with the knee close to full extension and in a valgus position (Boden et al, 2000; Olsen et al, 2004). Not surprisingly, the incidence of ACL injury is relatively high in sports such as basketball, netball, handball and volleyball that are characterised by a high frequency of landing, decelerating and rapid changes of direction (Arendt and Dick, 1995; Griffin et al, 2000). The incidence of non-contact ACL injury in females has been reported to be 6 to 8 times greater than in males competing in the same sports (Arendt and Dick, 1995; Chandy and Grana, 1985; Ferretti et al, 1992; Gray et al, 1985; Gwinn et al, 2000; Lidenfeld et al, 1994; Malone et al, 1993).

After initial contact with the ground during landing it takes between 30 ms and 75 ms for muscles to fully respond to changes in external loading (muscle latency) (Nigg et al, 1984; Watt and Jones, 1971). Consequently, muscles cannot fully respond to changes in external load that occur in less than the latency period of muscles. In these circumstances the body is forced to respond passively to the external load, referred to as passive loading. After the passive loading phase, the magnitude and direction of the ground reaction force is completely controlled by conscious muscular activity, referred to as active loading. By definition, the body is unable to control passive loading and therefore, the body is most vulnerable to injury from high passive loads. It is, perhaps, not surprising that ACL injury appears to occur most often just after initial ground contact (Boden et al, 2000; Olsen et al, 2004), i.e. during passive loading.

1.1 Landing/cutting kinematics.

Whilst the muscle moments about the joints of the lower limbs largely determine the movement patterns of the lower limbs, the resulting angular kinematics of the joints may provide some indication of strain on the passive support structures, especially the ligaments; the greater the range of abnormal joint movement, the greater the strain on associated ligaments (Watkins, 1999). A number of studies which have investigated the sagittal plane kinematics of landing and/or cutting manoeuvres report that females tend to land with the knees more extended 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 et al. 2003). A number of studies including Boden et al (2000) and Olsen et al (2004) have reported that non-contact ACL injury appears to occur more frequently when the knee is close to full extension than when flexed. Consequently, if females do tend to make ground contact with knees more extended than males, this may increase the risk of ACL injury relative to males.

A number of studies which have investigated the frontal plane kinematics of landing/cutting report that females tend to exhibit greater maximum knee valgus angle and greater range of motion when landing than 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 injury appears to occur more frequently when the knee exhibits a valgus movement (relative to normal upright standing position). Consequently, the reported greater maximum knee valgus angle in females when landing may increase the risk of ACL injury relative to males. A summary of the reported differences between males and females in lower limb sagittal and frontal plane kinemtaics in landing/cutting manoeuvres is shown in Table 1.

Table 1 about here.

Lack of standardisation in the demands of the tasks that subjects are required to perform will influence the movement patterns exhibited and reduce the likelihood of meaningful comparisons. For example, 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) may result in significantly different task demands. With regard to movement of the knee during landing and cutting manoeuvres, many studies only report absolute angular displacement – time data (Ford et al, 2003; Kernozek et al, 2005; Malinzak et al, 2001) with no reference to the subjects' natural lower leg alignments. There is considerable evidence that the Q angle, i.e. the acute angle between the line connecting anterior superior iliac spine to the middle of the patella and the line connecting the tibial tuberosity to the centre of the patella (Hungerford and Barry, 1979) is, on average, larger in females than males (Guerra et al, 1994; Herrington and Nester, 2004; Horton and Hall, 1989; Hsu et al, 1990). The larger Q angle in females may contribute to some extent to the larger maximum knee valgus angle reported in some studies for females on landing (Ford et al, 2003; Kernozek et al, 2005; Malinzak et al, 2001), but there would appear to be no reported data concerning change in lower leg alignment on landing relative to normal lower leg alignment in females or males.

1.2 Aim.

The aim of the study was to investigate the effects of gender on knee joint kinematics (absolute and relative) in university volleyball players performing block jump landings in opposed conditions.

2. Method.

2.1 Subjects.

6 female (Mean age 21.2 years ± 1.3, mass 57.6 kg ± 7.46 and height 164.8 cm ± 7.47) and 6 male (Mean age 21.6 years ± 3.29, mass 70.1 kg ± 3.05 and height 175.7 cm ± 8.56) university volleyball players participated in the study. All subjects were right leg dominant and had no previous history of hip, knee or

ankle injury. 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.

2.2 Measurement system.

Two adjacent AMTI force platforms embedded into the laboratory floor sampling at 600 Hz were used to measure ground reaction force to determine initial ground contact of right and left legs on landing. A 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). Based on a frequency content analysis of the 3D coordinate data, marker trajectories were filtered using a Woltring Filter with a low-pass cut-off frequency of 10 Hz and stop-band frequency of 30 Hz.

The laboratory was set up with a rope fixed horizontally to act as a volleyball net at a height of 2.43 m for male subjects and 2.24 m for female subjects. The net was placed 5 cm in front of and parallel to the adjacent force platforms (see Figure 1). In addition to the net, a volleyball was suspended from the ceiling so that it was positioned 5 cm above the height of the net 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). The ball was positioned vertically above the line separating the two force platforms.

Figure 1 about here.

2.3 Marker placement.

Markers were placed directly on each subject (on skin or on clothing covering the skin) in accordance with the Vicon system's lower body plug-in gait marker set. All subjects wore tight fitting clothing in order to minimise movement of markers relative to the anatomical locations they were intended to designate. From the location of the markers placed on the body, combined with required anthropometric measurements (height, weight, leg length, knee width and ankle width) of each subject, the Vicon system calculated the 3D coordinates of hip, knee and ankle joint centres.

2.4 Angular definitions.

In the plug-in gait system, the measurement of knee flexion/extension is based on the thigh axis (line connecting the hip joint and knee joint centres) and the shank axis (line connecting the knee and ankle joint centres) projected onto the plane of knee flexion/extension (as determined by the plug-in gait marker system). The flexion/extension angle is the angle between the distal extension of the thigh axis and the shank axis. A positive angle corresponds to knee flexion relative to the fully extended position (Figure 2).

Figure 2 about here.

The measurement of knee valgus/varus is based on the thigh axis and the shank axis projected onto the plane of knee valgus/varus (defined as perpendicular to the knee flexion/extension axis). The valgus/varus angle is the angle between the distal extension of the thigh axis and the shank axis. A positive angle indicates varus and a negative angle indicates valgus (Figure 3).

Figure 3 about here.

2.5 Static reference position.

Prior to dynamic trials, a static trial was recorded for each subject while standing in the normal upright position. The purpose of the static trial was to provide reference data for knee flexion/extension, knee valgus/varus, in order to facilitate analysis of knee motion in dynamic trials. Subjects were instructed to stand still with their feet placed apart at a standardised distance of 10% of their leg length.

2.6 Landing Task.

The jumping and landing task was made as realistic as possible by having subjects attempt to block an actual spike performed by an experienced volleyball player. At the start of each trial, the subject stood with each foot on a separate force plate. The subject then timed his/her blocking action in order to try to block the ball as it was spiked. The ball was spiked from the same suspended position in order to eliminate variation in the position and velocity of the ball. On landing, each foot landed on a separate force plate. Following appropriate warm up and practice, data was recorded for three successful trials for each subject.

2.7 Data analysis.

The angular displacement of the knee in the sagittal (flexion/extension) and frontal (valgus/varus) planes was determined between initial ground contact (IC) and (depending on which occurred later in each trial) either maximum flexion or maximum valgus angle (MAX). The angular displacement – time data were then normalised with respect to average trial time for both legs combined and for separate dominant and non-dominant legs. Average angular velocity in the sagittal and frontal planes was determined for combined dominant and non-dominant legs during the passive (PP) and active (AP) phases of landing. Independent-samples t-tests were carried out on the angular displacement and angular velocity data to examine gender differences and differences between dominant and non-dominant legs.

3. Results.

All Figures show variables plotted against normalised time and against absolute mean trial time between IC and MAX. Absolute mean contact time was 0.190 s ± 0.040 for males and 0.194 s ± 0.057 for females. As there was no significant difference between contact time for males and females, mean contact time of 0.192 s was used. Static reference data is reported in Table 2. There was no significant difference between males and females knee flexion/extension, knee valgus/varus angles in the static reference position.

Table 2 about here.

3.1 Sagittal plane kinematics.

3.1.1 Absolute changes in knee flexion.

In the sagittal plane, females exhibited significantly less knee flexion at IC, greater MAX knee flexion and significantly greater ROM of knee flexion than males (Table 3 and Figure 4). Males and females showed no significant difference in sagittal plane kinematics between dominant and non-dominant legs during landing (Table 4 and Figures 5 and 6). The magnitude of the standard deviation of the knee flexion data (combined and for each leg) at 1% normalised time intervals was very similar between IC and MAX. This is illustrated in Figure 4.

Table 3 about here.

Figure 4 about here.

Table 4 about here.

Figure 5 about here.

Figure 6 about here.

Figure 4 indicates differences between males and females in average angular velocity of knee flexion during PP and AP. Females displayed significantly greater average knee flexion angular velocity than males during PP, but average knee flexion angular velocity during AP was similar for males and females (Table 5).

Table 5 about here.

3.1.2 Relative changes in knee flexion.

Relative to the static reference position in the sagittal plane, there was no significant difference between males and females in knee flexion at IC. Females, however, displayed significantly greater MAX knee flexion than males (Table 3).

3.2 Frontal plane kinematics.

3.2.1 Absolute changes in knee valgus/varus.

In the frontal plane, females tended to contact the ground in a slight valgus position which progressively increased between IC and MAX. In contrast, males tended to contact the ground in a slight valgus position and moved into a slight varus at MAX (Table 3 and Figure 7). The amount of valgus at IC was not significantly different between males and females. However, the ROM and the MAX valgus angle were significantly greater in females compared to males

(Table 3 and Figure 7). Males showed no significant difference in frontal plane kinematics between dominant and non-dominant legs during landing (Table 4 and Figure 5). However, females' non-dominant leg displayed significantly greater maximum knee valgus angle and range of motion compared to the dominant leg (Table 4 and Figures 6).

Figure 7 indicates differences between males and females in average angular velocity of knee valgus/varus during PP and AP (Table 5). Females displayed significantly greater average knee valgus angular velocity than males during PP. During AP, the average knee varus angular velocity exhibited by males was similar to the average knee valgus angular velocity exhibited by females.

Figure 7 about here.

3.2.2 Relative changes in knee valgus/varus.

In the frontal plane, the relative amount of valgus at IC was not significantly different between males and females. Females, however, displayed significantly greater MAX knee valgus angle than males (Table 3).

4. Discussion.

4.1 Sagittal plane kinematics.

Table 3 and Figure 4 show that females tended to land with less absolute knee flexion than males, a finding strongly supported by previous literature (Decker et al, 2003; James et al, 2004; Malinzak et al, 2001; Yu et al., 2006). The more extended the knees on ground contact, the greater the risk of ACL strain (Li et al, 1999; Nunley et al, 2003). Maximum absolute knee flexion angle and range of motion of knee flexion was found to be significantly greater in females than males, contrary to a number of other studies (Salci et al, 2004; Yu et al, 2006). These differences could be due to different task demands. The present study involved an opposed jumping and landing task, whereas the Salci et al (2004) and Yu et al (2006) studies involved an unopposed landing task.

Females displayed significantly greater average knee flexion angular velocity during PP than males, but there was no significant difference in average knee flexion angular velocity between males and females during AP. During PP, the lower limb muscles do not have complete control over the landing manoeuvre and therefore, the significantly greater average knee flexion angular velocity during PP in the females may indicate less dynamic stability of the knee than males during PP. The lower the level of dynamic stability, the greater the dependence on passive support structures, especially ligaments, for the maintenance of joint stability. Ligament strain is more likely as joint angular velocity increases due to the time required by the neuromuscular system to control the movement. Consequently, the significantly greater knee flexion angular velocity during PP in females may increase the likelihood of ACL strain compared to males.

Relative to the static reference position, there was no significant difference between males and females knee flexion at IC (Table 3). This suggests that the reduced absolute knee flexion at IC in females compared to males may, to some extent, be accounted for by their natural lower limb alignment, i.e. knees more extended in females than males during normal upright standing (Table 2). Females, however, showed significantly greater MAX relative knee flexion than males (Table 3).

When comparing the motion of the dominant and non-dominant legs in the sagittal plane (Figures 5 and 6 and Table 4), no significant differences were observed at IC, MAX or for ROM for males or females. This indicates a highly symmetrical landing pattern in the sagittal plane which, it is reasonable to assume, would facilitate greater dynamic balance during landing compared to a less symmetrical pattern.

4.2 Frontal plane kinematics.

Table 3 and Figure 7 show that females exhibited significantly greater absolute and relative maximum knee valgus angle and significantly greater range of motion of knee valgus angle than males. A number of studies have reported greater absolute maximum knee valgus angle and greater absolute knee valgus range of motion in females compared to males (Ford et al, 2003; Kernozek et al, 2005; Malinzak et al, 2001). However, no other studies have reported comparable relative data. The greater relative maximum knee valgus angle displayed by females compared to males in this study suggests that the reported greater absolute maximum knee valgus angle in females compared to males during landing tasks (Ford et al, 2003; Kernozek et al, 2005; Malinzak et al, 2001) is unlikely to have been accounted for by differences in static lower limb alignments.

When comparing dominant and non-dominant legs in males (Figure 5 and Table 4), no significant difference was observed in valgus/varus angles at IC, MAX or ROM. Females, however, showed significantly greater MAX knee valgus angle and ROM in the non-dominant limb compared to the dominant limb (Figure 6 and Table 4). These results may indicate a higher level of dynamic stability in males compared to females.

As with knee flexion, females displayed significantly greater average knee valgus angular velocity than males during PP (Table 5), but there was no significant difference in average knee angular velocity between males (varus) and females (valgus) during AP. The combination of significantly greater knee flexion angular velocity in females during PP, significantly greater knee valgus angular velocity in females during PP, significantly greater maximum knee valgus angle during landing in females and significantly greater knee valgus

ROM during landing in females may reflect lower dynamic stability and, in turn, increased risk of knee ligament strain.

Increased knee valgus angle (relative to static reference position) is a major risk factor for ACL injury (Olsen et al, 2004; Boden et al, 2000). It appears that females are vulnerable to excessive knee valgus motion during the PP which, in turn, is likely to increase the risk of ACL strain.

In conclusion, the results suggest less dynamic stability of the knee in females compared to males in the passive phase. The lower the dynamic stability, the greater the dependence on the passive support structures, especially the ligaments, for the maintenance of joint stability. As ACL injuries occur most frequently in the passive phase of landing manoeuvres, the present results suggest that lack of dynamic stability of the knee in the passive phase could be a contributory factor in the reported greater incidence of ACL injury in females compared to males. Training programmes for females should incorporate exercises and practices to improve the dynamic stability of the knee in the passive phase of ground contact.

Table 1.

Study.	**Task**	**Sagittal plane kinematics.**	**Frontal plane kinematics.**
Salci et al, (2004)	40 cm and 60 cm vertical drop landing.	F displayed smaller maximum knee flexion angles than M (M: 79.6 ± 17.9°; F: 59.3 ± 9.5°)	
Decker et al, (2003)	60 cm vertical drop landing.	F had smaller knee flexion at ground contact (M: 30.0 ± 7.7°; F: 22.8 ± 8.0°) and greater range of motion (M: 63.4 ± 9.3°; F: 75.8 ± 9.1°) than M.	
Ford et al, (2003)	31 cm vertical drop-jump landing.		Increased knee valgus motion (M: 5.3 ± 0.5 cm; F: 7.3 ± 0.5 cm) and maximum angle (M: 14.25 ± 1.95°; F: 20.05 ± 2.5°) in F compared to M.
Malinzak et al, (2001)	Running, side-cutting and cross-cutting.	F displayed smaller knee flexion throughout stance phase than M (mean of 8° less throughout stance phase. No absolute mean data provided).	F exhibited greater knee valgus angle throughout stance phase than M (mean of 11° more throughout stance phase. No absolute mean data provided).
James et al, (2004)	Cutting.	F exhibited smaller knee flexion at ground contact than M (M: 46.0 ± 8.05°; F: 40.2 ± 8.04°).	
Kernozek et al, (2005)	60 cm vertical drop landing.		F exhibited greater peak (M: -0.66 ± 6.90°; F: 24.85 ± 8.45°) and range of motion (M: 7.08 ± 6.61°; F: 26.50 ± 9.00°) of knee valgus angle than M.
Yu et al, (2006)	Stop-jump landing.	F exhibited smaller knee flexion at ground contact (M: 31.92 ± 10.30°; F: 23.95 ± 8.31°) and smaller maximum knee flexion (M: 77.36 ± 10.59°; F: 68.54 ± 9.28°) than M.	

F = females, M = males.

Table 2.

		Male	Female
Knee flexion (+ve) / extension (–ve) (^{o})	Left	4.28 ± 5.75	2.87 ± 3.31
	Right	5.07 ± 2.61	2.63 ± 4.37
	Mean of left and right	4.68 ± 4.23	2.75 ± 3.66
Knee varus (+ve) / valgus (–ve) (^{o})	Left	-0.15 ± 3.60	-1.39 ± 3.47
	Right	-2.72 ± 3.61	-2.74 ± 2.47
	Mean of left and right	-1.43 ± 3.66	-2.06 ± 2.93

* No significant differences between males and females in the static reference position.

Table 3.

		Males		Females	
		Absolute (°)	Relative (°)	Absolute (°)	Relative (°)
Flexion	IC	19.39 ± 6.36[1]	14.71 ± 6.36	15.11 ± 6.15[1]	12.36 ± 6.15
	MAX	62.09 ± 11.60[2]	57.41 ± 11.60[3]	68.24 ± 12.15[2]	65.49 ± 12.15[3]
	ROM	42.7 ± 13.88[4]	N/A	53.14 ± 13.08[4]	N/A
Valg/var	IC	-2.78 ± 5.89	-1.35 ± 5.89	-1.57 ± 2.83	0.49 ± 2.83
	MAX_{VAL}	-2.93 ± 7.89[5]	-1.50 ± 7.89[6]	-10.35 ± 7.71[5]	-8.29 ± 7.71[6]
	MAX_{VAR}	0.56 ± 9.12	1.99 ± 9.12	N/A	N/A
	ROM	3.49 ± 9.64[7]	N/A	8.78 ± 7.80[7]	N/A

[1 - 7]: Significant difference between males and females ($P < 0.01$).

Table 4.

		Males		Females	
		Non-dominant	Dominant	Non-dominant	Dominant
Flexion (°)	IC	17.12 ± 6.38	21.67 ± 5.67	16.68 ± 6.11	13.53 ± 5.97
	MAX	61.21 ± 12.28	62.97 ± 11.24	68.27 ± 14.69	68.22 ± 9.49
	ROM	44.09 ± 15.05	41.31 ± 12.96	51.58 ± 13.86	54.69 ± 12.53
Valg/var (°)	IC	-4.01 ± 5.64	-1.56 ± 6.06	-1.07 ± 2.65	-2.06 ± 3.00
	MAX	2.5 ± 8.93	-1.38 ± 9.20	-13.91 ± 8.71[1]	-6.79 ± 4.50[1]
	ROM	6.51 ± 12.00	0.18 ± 5.19	12.83 ± 7.59[2]	4.73 ± 5.77[2]

[1 + 2] significant difference between dominant and non-dominant legs in females ($P < 0.01$).

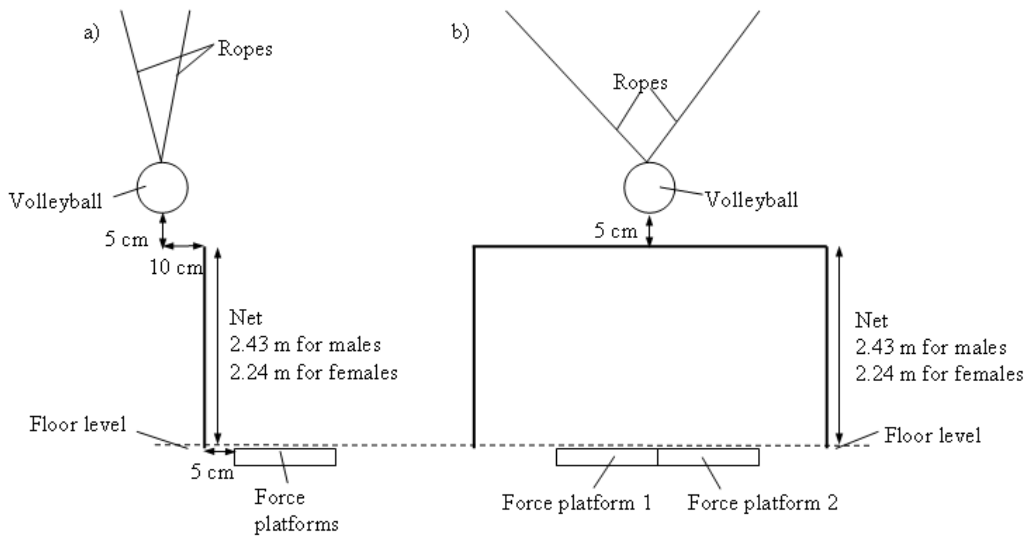
Table 5.

		Passive phase						
		t_{IC} (s)	t_{PP} (s)	Δt (s)	θ_{IC} (°)	θ_{PP} (°)	$\Delta\theta$ (°)	ω (rad·s^{-1})
Flexion	Males	0	0.075	0.075	19.39	42.85	23.46	5.46[1]
	Females	0	0.075	0.075	15.11	47.24	32.13	7.48[1]
Valg/var	Males	0	0.075	0.075	-2.78	-2.91	0.13	0.03[2]
	Females	0	0.075	0.075	-1.57	-6.05	4.48	1.04[2]
		Active phase						
		t_{PP} (s)	t_{MAX} (s)	Δt (s)	θ_{PP} (°)	θ_{MAX} (°)	$\Delta\theta$ (°)	ω (rad·s^{-1})
Flexion	Males	0.075	0.192	0.117	42.85	61.9	19.05	2.84
	Females	0.075	0.192	0.117	47.24	67.45	20.21	3.01
Valg/var	Males	0.075	0.192	0.117	-2.91	0.56	3.47	0.52
	Females	0.075	0.192	0.117	-6.06	-10.24	4.19	0.62

[1 + 2]: significant difference between males and females ($P < 0.01$).

t_{IC} = time at IC; t_{PP} = duration of PP; t_{MAX} = time at MAX; θ_{IC} = angle at IC; θ_{PP} = angle at end of PP; θ_{MAX} = angle at MAX; ω = average angular velocity.

Figure 1.



a)
Ropes
Volleyball
5 cm
10 cm
Net
2.43 m for males
2.24 m for females
Floor level
5 cm
Force
platforms
b)
Ropes
Volleyball
5 cm
Net
2.43 m for males
2.24 m for females
Floor level
Force platform 1
Force platform 2

Figure 2.

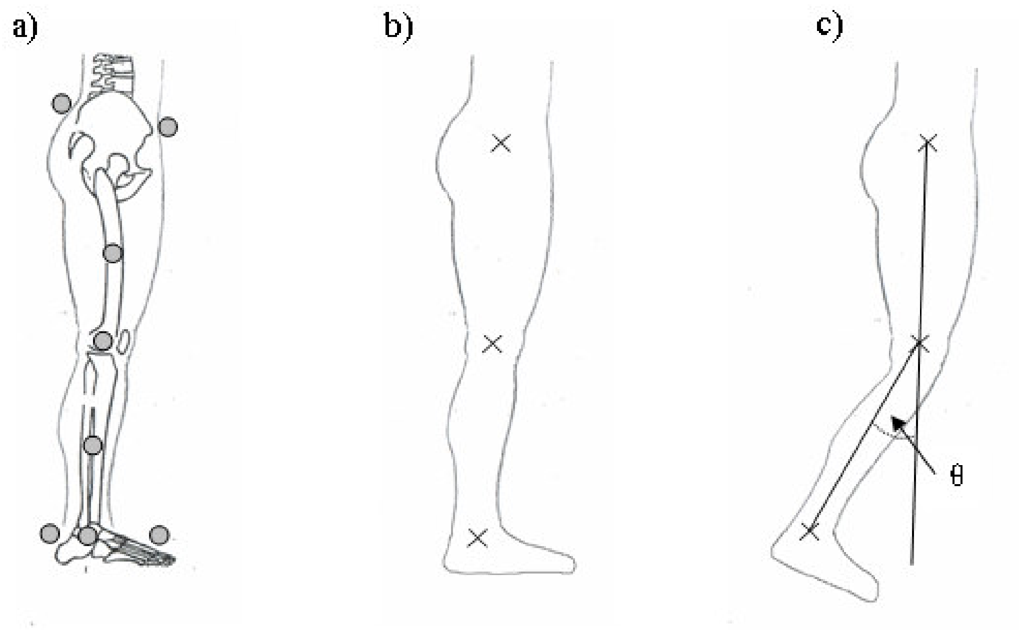


Figure 3.

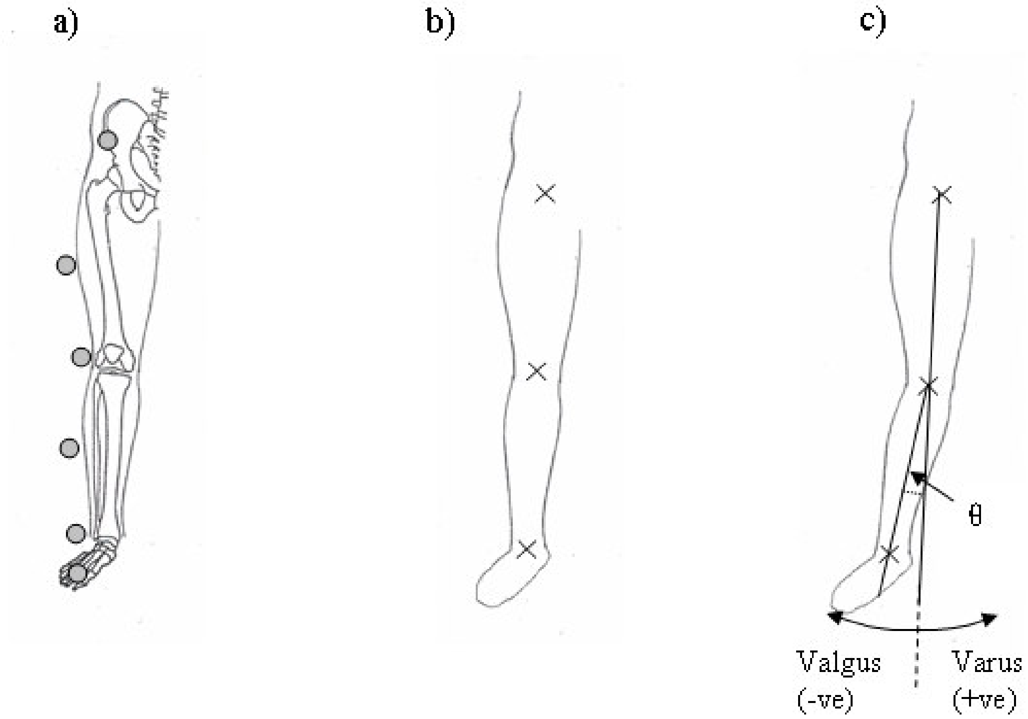
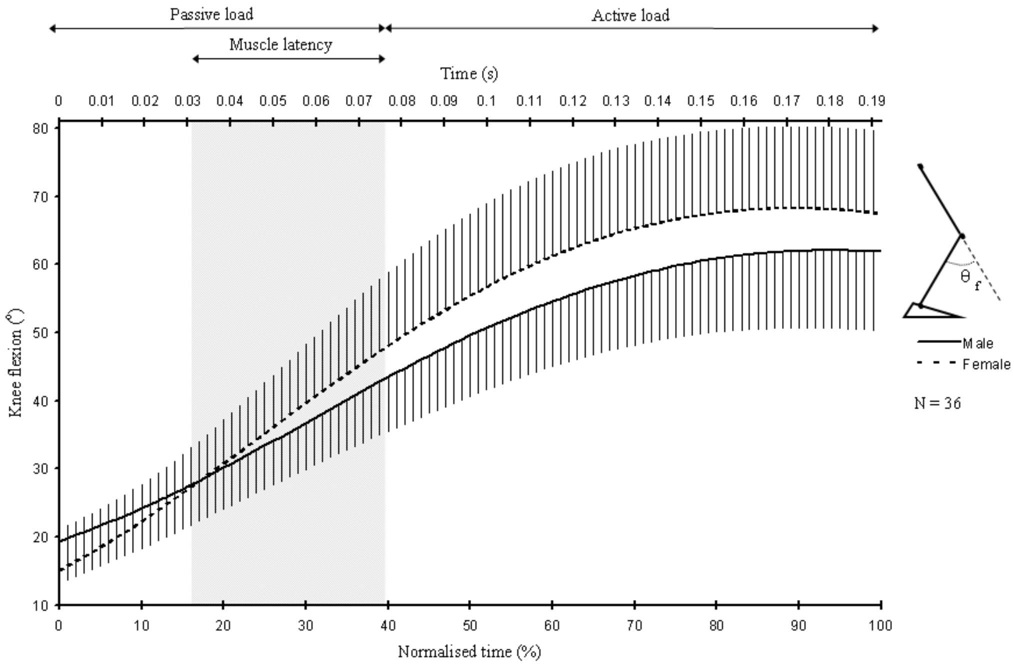
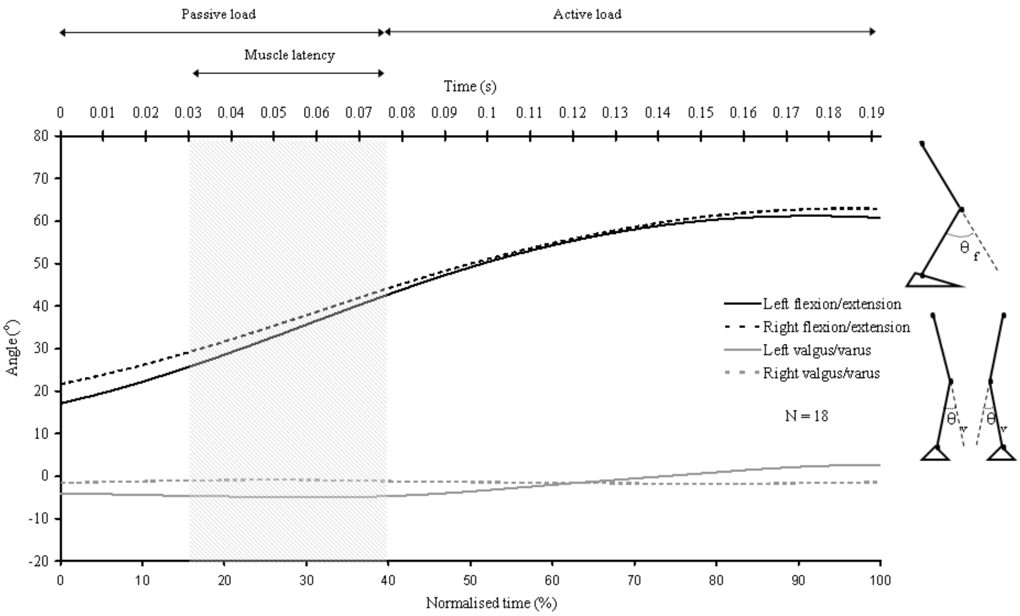


Figure 4.



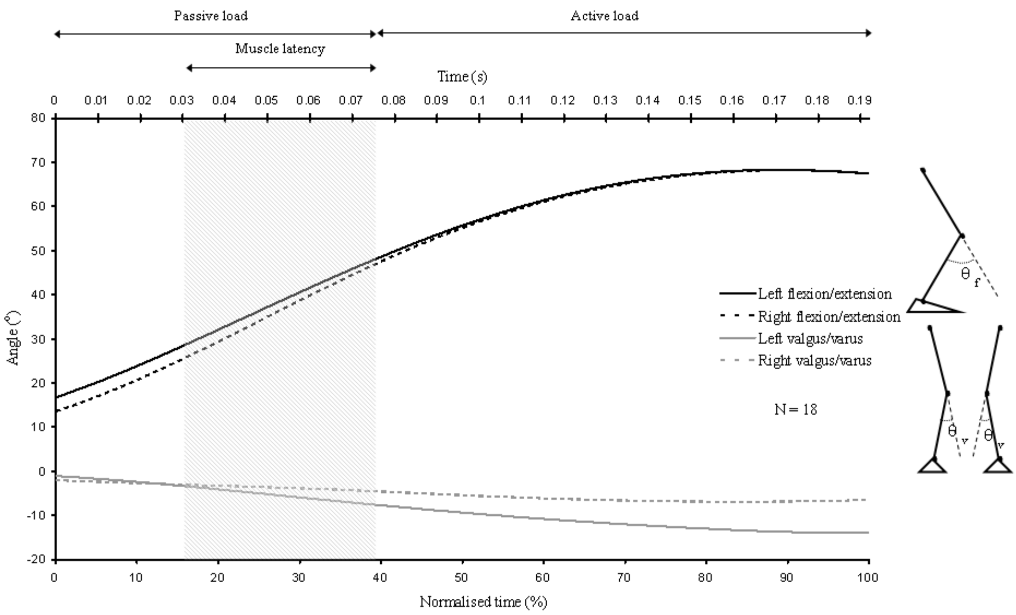
Passive load
Active load
Muscle latency
Time (s)
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1 0.11 0.12 0.13 0.14 0.15 0.16 0.17 0.18 0.19
Knee flexion (°)
10 20 30 40 50 60 70 80
0 10 20 30 40 50 60 70 80 90 100
Normalised time (%)
θ f
Male
Female
N = 36

Figure 5.



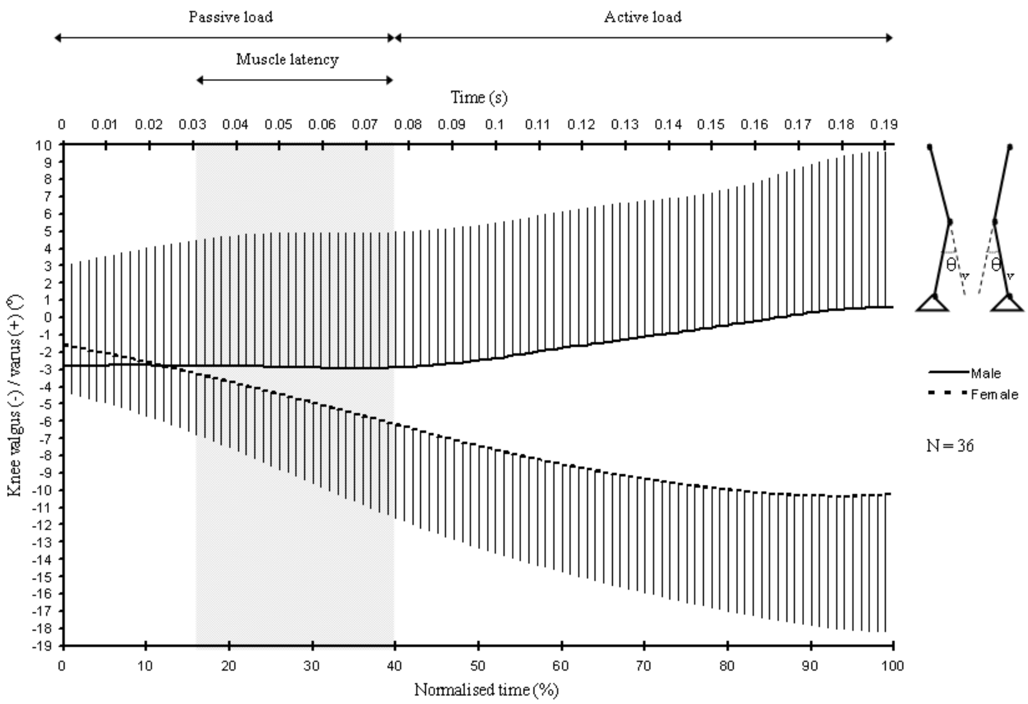
Passive load
Active load
Muscle latency
Time (s)
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1 0.11 0.12 0.13 0.14 0.15 0.16 0.17 0.18 0.19
80 70 60 50 40 30 20 10 0 -10 -20
Angle (°)
Left flexion/extension
Right flexion/extension
Left valgus/varus
Right valgus/varus
N = 18
θ f
θ v
θ v
0 10 20 30 40 50 60 70 80 90 100
Normalised time (%)

Figure 6.



Passive load
Active load
Muscle latency
Time (s)
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1 0.11 0.12 0.13 0.14 0.15 0.16 0.17 0.18 0.19
Angle (°)
80 70 60 50 40 30 20 10 0 -10 -20
Left flexion/extension
Right flexion/extension
Left valgus/varus
Right valgus/varus
N = 18
θf
θv
0 10 20 30 40 50 60 70 80 90 100
Normalised time (%)

Figure 7.



Passive load
Active load
Muscle latency
Time (s)
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1 0.11 0.12 0.13 0.14 0.15 0.16 0.17 0.18 0.19
Knee valgus (-) / varus (+) (°)
Normalised time (%)
Male
Female
N = 36

Table legends.

Table 1. Sagittal and frontal plane kinematics in landing/cutting movements in males and females (mean ± standard deviation).

Table 2. Group mean results for knee flexion/extension and knee valgus/varus angles in the static reference position for males and females (mean ± standard deviation) *.

Table 3. Group mean results for absolute and relative (angle measured during dynamic trial minus angle measured during static reference trial) knee flexion/extension and valgus/varus (– varus; + valgus) angles at IC, MAX and ROM (mean ± standard deviation).

Table 4. Group mean results for absolute knee flexion/extension and valgus/varus (– varus; + valgus) at IC, MAX and for ROM for male and female subjects' dominant and non-dominant legs (mean ± standard deviation).

Table 5. Angular velocity of knee flexion and valgus/varus during the passive and active loading phases of landing.

Figure legends.

Figure 1. Laboratory set up; a) left lateral aspect, b) frontal aspect.

Figure 2. Knee flexion/extension: see text for definition. a) Markers placed on skin over bone landmarks. b) Derived estimated joint centres. c) Knee flexion/extension angle θ.

Figure 3. Knee valgus/varus: see text for definition. a) Markers placed on skin over bone landmarks. b) Derived estimated joint centres. c) Knee valgus/varus angle θ.

Figure 4. Knee flexion (θ_f) between IC and MAX for males and females. The standard deviation at 1% normalised time intervals in indicated by the vertical lines.

Figure 5. Dominant and non-dominant leg knee flexion/extension (θ_f) and valgus (–ve) / varus (+ve) (θ_v) between IC and MAX for males.

Figure 6. Dominant and non-dominant leg knee flexion/extension (θ_f) and valgus (–ve) / varus (+ve) (θ_v) between IC and MAX for females.

Figure 7. Knee valgus/varus (θ_v) between IC and MAX for males and females. The standard deviation at 1% normalised time intervals in indicated by the vertical lines.

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