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# The Effects of Opposition and Gender on Knee Kinematics and Ground Reaction Force During Landing From Volleyball Block Jumps

Gerwyn Hughes

*University of San Francisco*, ghughes@usfca.edu

James Watkins

Nick Owen

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

3

4 Corresponding author: Dr. Gerwyn Hughes.

5 Postal Address: Division of Sport, Health and Exercise, University of Hertfordshire,  
6 College Lane, Hatfield, AL10 9AB.

7 Email: g.hughes@herts.ac.uk

8 Telephone: + 44 1707289430

9

10 Author information: Gerwyn Hughes is a lecturer in the Division of Sport Health and  
11 Exercise at the University of Hertfordshire, UK. James Watkins is a Professor and Nick  
12 Owen is a lecturer in the Department of Sports Science at Swansea University, UK.

13

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

16

17 **Abstract**

18           The aim of the study was to examine the effect of opposition and gender on knee  
19 kinematics and ground reaction force during landing from a volleyball block jump. Six  
20 female and six male university volleyball players performed two landing tasks 1) an  
21 unopposed and 2) an opposed volleyball block jump and landing. Knee kinematics were  
22 recorded by a 12 camera motion analysis system (120 Hz) and ground reaction force was  
23 recorded by a force platform (600 Hz) during landing. The results showed a significant effect  
24 for level of opposition in peak normalized GRF ( $p = .04$ ), knee flexion at ground contact ( $p =$   
25  $.003$ ), maximum knee flexion ( $p = .001$ ) and range of motion of knee flexion ( $p = .003$ ).  
26 There was a significant effect for gender in maximum knee flexion ( $p = .01$ ), range of motion  
27 of knee flexion ( $p = .001$ ), maximum knee valgus angle ( $p = .001$ ) and range of motion of  
28 knee valgus ( $p = .001$ ). The changes in landing biomechanics as a result of opposition suggest  
29 future research investigating landing mechanics should examine opposed exercises since  
30 opposition may significantly alter neuromuscular responses.

31

32 **Key words:**                           Biomechanics, ACL injury, opposed.

33

34 The effects of opposition and gender on knee kinematics and ground reaction force during  
35 landing from volleyball block jumps.

36 Research suggests that approximately 70% of anterior cruciate ligament (ACL)  
37 injuries occur in sporting activities (Faegin, 1988; Johnson, 1988; Smith, Livesay, & Woo,  
38 1988). Studies examining the etiology of ACL injuries report that between 70% and 90% of  
39 injuries occur in non-contact situations (Griffin et al., 2000; McNair, Marshall, & Matheston,  
40 1993; Mykelbust, Maehlum, Engbretsen, Strand, & Solheim, 1997). Furthermore, the  
41 incidence of ACL injuries is high in sports which involve a high frequency of landing  
42 (Hopper & Elliot, 1993), decelerating (Miller, Cooper, & Warner, 1995) or rapidly changing  
43 direction (Arendt & Dick, 1995; Griffin et al., 2000; Olsen, Mykelbust, Engebretsen, & Bahr,  
44 2004), such as basketball, netball, handball and volleyball. The incidence of non-contact ACL  
45 injuries have been reported to be 6 to 8 times greater in females than in males competing in  
46 the same sports (Arendt & Dick, 1995; Chandy & Grana, 1985; Ferretti, Papandrea,  
47 Conteduca, & Mariani, 1992; Gray et al., 1985; Gwinn, Wilckens, McDevitt, Ross, & Kao,  
48 2000; Lidenfeld, Schmitt, Hendy, Mangine, & Noyes, 1994; Malone, Hardaker, Garrett,  
49 Feagin, & Bassett, 1993).

50 Since ACL injuries have been associated with landing, decelerating and rapidly  
51 changing direction, a number of studies have investigated gender differences the  
52 biomechanics associated with these maneuvers (Decker, Torry, Wyland, Sterett, & Steadman,  
53 2003; Ford, Myer, & Hewett, 2003; James, Sizer, Starch, Lockhart, & Slauterbeck, 2004;  
54 Kernozek, Torry, Van Hoof, Cowley, & Tanner, 2005; Malinzak, Colby, Kirkendall, Yu, &  
55 Garrett, 2001; Yu, Lin, & Garrett, 2006). Studies examining sagittal plane kinematics of  
56 landing and cutting maneuvers report that females tend to land with less knee flexion angle  
57 than males (Decker et al., 2003; James et al., 2004; Malinzak et al., 2001; Yu et al., 2006) and  
58 exhibit a greater range of knee flexion than males (Decker et al., 2003). Due to the effect of

59 knee flexion on the patella tendon-tibia shaft angle, when a given load is acting through the  
60 patellar ligament there is likely to be a greater strain placed on the ACL if the knee flexion  
61 angle is small (Li et al., 1999; Nunley, Wright, Renner, Yu, & Garrett, 2003). A number of  
62 observational studies including Boden et al. (2000) and Olsen et al. (2004) have reported that  
63 non-contact ACL injuries most frequently occur immediately following initial ground contact  
64 with the knee close to full extension. Consequently, since females tend to make contact with  
65 the ground with knees in a more extended position than males, the risk of ACL injury may be  
66 greater in females relative to males. Studies investigating frontal plane kinematics of landing  
67 and cutting report that females tend to exhibit greater maximum knee valgus angle and  
68 greater knee valgus angle range of motion compared to males (Ford et al., 2003; Kernozek et  
69 al., 2005; Malinzak et al., 2001). Boden et al. (2000) and Olsen et al. (2004) have reported  
70 that non-contact ACL injuries appear to occur more frequently when the knee exhibits a  
71 valgus movement. Consequently, greater maximum knee valgus angle in females may  
72 increase the risk of ACL injury relative to males. Some studies also suggest that females  
73 exhibit greater normalized peak ground reaction force (GRF) during landing than males  
74 (Kernozek et al., 2005; Salci, Kentel, Heycan, Akin, & Korkusus, 2004; Yu et al., 2006). The  
75 greater the GRF exhibited during landing, the greater the likely load on the passive support  
76 structures of the knee and therefore the greater the likelihood of injury (Devita & Skelly,  
77 1992).

78         The demands of the tasks that participants are required to perform will influence the  
79 movement patterns exhibited and therefore influence the validity of comparisons made  
80 between males and females. Previous studies examining landing biomechanics in males and  
81 females typically use tasks involving a stop-jump (Chappell, Yu, Kirkendall, & Garrett, 2002;  
82 Yu et al., 2006; Yu et al., 2005), a maximum height vertical jump (Hewett, Stroupe, Nance,  
83 & Noyes, 1996; Swartz, Decoster, Russell, & Croce, 2005) or dropping down from a raised

84 platform set at the same height for both males and females (Decker et al., 2003; Ford et al.,  
85 2003; Kernozek et al., 2005; Salci et al., 2004). Dropping down from a raised platform may  
86 result in significantly different task demands for females compared to males (females are less  
87 likely to jump as high as females), particularly in sports such as volleyball where the net is set  
88 at a different height for males and females (2.48 m for males and 2.29 m for females).  
89 Therefore, a lack of standardization in the task participants are required to perform in  
90 previous studies may have reduced the likelihood of meaningful comparison between males  
91 and females. Previous studies have found changes in technique as a result of opposition  
92 (Davila, Garcia, Montilla, & Ruiz, 2006). For example, Davila et al. (2006) found significant  
93 changes in technique were made by a handball players when shooting during unopposed and  
94 opposed conditions. It is reasonable to assume that the attentional demand of jumping and  
95 landing in an opposed context will be less than that in an unopposed context (Chen et al.,  
96 1996; Lajoie, Teasdale, Bard, & Fleury, 1993) which, in turn, is likely to affect the  
97 neuromuscular response when landing. Despite this, the vast majority of studies examining  
98 gender differences in kinematics and kinetics during landing and cutting maneuvers use an  
99 unopposed task (Decker et al., 2003; Kernozek et al., 2005; Salci et al., 2004; Yu et al.,  
100 2006), with only a small number of studies examining opposed tasks (Hughes, Watkins,  
101 Owen, & Lewis, 2007) or during game-like situations involving activities such as catching a  
102 ball (Cowling & Steele, 2001). In addition, direct comparison of the results is not possible  
103 due to differences in task demands. To our knowledge, no study has examined gender  
104 differences in knee kinematics and GRF when performing sport specific landing tasks during  
105 both unopposed and opposed conditions. The purpose of the present study was to examine the  
106 effect of opposition and gender on knee kinematics and GRF during landing from a volleyball  
107 block jump in male and female university volleyball players.

108

## 109 **Method**

### 110 **Participants**

111           The participants were 6 female (Mean age  $21.2 \pm 1.3$  years, mass  $57.6 \pm 7.5$  kg and  
112 height  $164.8 \pm 7.5$  cm) and 6 male (Mean age  $21.6 \pm 3.3$  years, mass  $70.1 \pm 3.1$  kg and height  
113  $175.7 \pm 8.6$  cm) university volleyball players. All participants had no previous history of hip,  
114 knee or ankle injury and were right leg dominant. Ethical approval was granted for the study  
115 by the University Ethics Committee and written consent forms were signed by all participants  
116 prior to data collection. The present study is part of a larger investigation examining landing  
117 biomechanics, of which some data has been previously published (Hughes et al., 2007).

118

### 119 **Measurement System**

120           An AMTI force platform sampling at 600 Hz was used to measure the GRF of the  
121 right (dominant) leg during landing. A time synchronized 12 camera Vicon 512 system  
122 (Vicon, Oxford, England) sampling at 120 Hz was used to determine 3D coordinates of 16  
123 retro-reflective markers (25 mm diameter). Markers were placed directly on the skin over  
124 anatomical landmarks in accordance with the Vicon system's lower body plug-in gait marker  
125 set. From the location of the markers placed on the body, combined with required  
126 anthropometric measurements of each participant entered into the system, the Vicon system  
127 calculated the 3D coordinates of hip, knee and ankle joint centers. In the plug-in gait system,  
128 the measurement of knee flexion angle and valgus/varus angle was determined as the Euler  
129 angle of the shank segment reference frame relative to the thigh segment reference plane  
130 rotated in the order 1) flexion/extension, 2) valgus/varus, 3) internal/external rotation.

131

### 132 **Tasks**



133 Prior to data collection all participants performed a 10-min warm up consisting of  
134 lower limb stretching and running/jogging on a treadmill at self determined speeds. When  
135 this was completed, participants practiced the jumping and landing tasks until comfortable  
136 with the procedure. To carry out the landing task, a rope was fixed horizontally 5 cm in front  
137 of the force platform to act as a volleyball net at a height of 2.43 m for male participants and  
138 2.24 m for female participants (height of a standard volleyball net). Also, a volleyball was  
139 suspended from the ceiling and positioned with the bottom of the ball 5 cm above the net  
140 (2.48 m for males and 2.29 m for females) and with the centre of the ball 10 cm in front of  
141 the line of the net (the other side of the net to where the participant (blocker) was standing).  
142 This was considered to be a typical position from which a volleyball is spiked from during a  
143 game. Participants were required to perform two landing tasks: unopposed volleyball block  
144 jump and landing and opposed volleyball block jump and landing. 1) Unopposed: At the start  
145 of each trial, the participant stood with their right foot on the force plate. The participant was  
146 then instructed to jump up and pretend to block the suspended volleyball. On landing, the  
147 right foot landed on the force plate. To standardize the unopposed blocking task, it was  
148 ensured that participants' hands reached the height of the top of the suspended volleyball in  
149 each trial. 2) Opposed: At the start of each trial, the participant stood with their right foot on  
150 the force plate. The participant then timed his/her blocking action in order to try to block the  
151 ball as it was spiked. In all trials, the person spiking the volleyball was of a similar playing  
152 standard to the blocker. The ball was spiked from the same suspended position in order to  
153 eliminate variation in the position and velocity of the ball. On landing, the right foot landed  
154 on the force plate. Data were recorded for three successful trials for each landing task for  
155 each participant. Trials where the entire right foot alone did not land on the force plate were  
156 discarded.

157

## 158 Data Analysis

159           The data were filtered using a Woltring Filter. Through a frequency content analysis  
160 of the 3D coordinate data, the filter setting was determined as a low-pass filter of cut-off  
161 frequency 10 Hz and stop-band frequency of 30 Hz. The GRF and knee angle in the sagittal  
162 (flexion/extension) and frontal (valgus/varus) planes were determined between initial ground  
163 contact (IC) and, depending on which occurred later in the trial, either maximum knee flexion  
164 or maximum knee valgus/varus angle (MAX) in each trial. Angular displacement mean data  
165 (IC, MAX and range of motion (ROM)) were based on 36 trials for both males and females  
166 (6 participants  $\times$  3 trials  $\times$  2 legs). GRF data were normalized to body weight (in Newtons)  
167 and mean data were based on 18 trials for both males and females (6 participants  $\times$  3 trials  $\times$   
168 1 leg). All statistical analysis was performed using SPSS version 14.0 (SPSS Inc, Chicago,  
169 IL). Mixed between-within participants analysis of variance (SPANOVA) was carried out on  
170 the data to examine the effects of the level of opposition and the effects of gender on angular  
171 displacement in the sagittal and frontal planes and normalized GRF, where the alpha level  
172 was set at  $p < 0.05$ .

173

## 174 **Results**

175           For all variables, there was no significant interaction between the level of opposition  
176 (unopposed/opposed) and gender (females/males) ( $p > .05$ ). All Figures show variables  
177 plotted against normalized time and against absolute mean trial time between IC and MAX.  
178 For the unopposed trials, absolute mean trial time was  $0.203 \text{ s} \pm 0.068$  for males and  $0.213 \text{ s}$   
179  $\pm 0.061$  for females. For the opposed trials, absolute mean trial time was  $0.190 \text{ s} \pm 0.040$  for  
180 males and  $0.194 \text{ s} \pm 0.057$  for females. As there was no significant effect for level of  
181 opposition (Wilks Lambada = .95,  $F = 3.18$ ,  $p = .08$ , partial eta squared = .05) or for gender

182 ( $F = 1.16, p = .29, \text{partial eta squared} = .02$ ) for contact time, a mean trial time of 0.200 s was  
183 used.

184

### 185 Effects of Opposition

186 In the sagittal plane, there was a significant effect for level of opposition for knee  
187 flexion at IC (Wilks Lambda = .86,  $F = 9.68, p = .003, \text{partial eta squared} = .14$ ) with greater  
188 knee flexion observed at IC during unopposed trials than opposed trials (Table 1 and Figure  
189 1). There was a significant effect for level of opposition (Wilks Lambda = .77,  $F = 17.6, p =$   
190  $.001, \text{partial eta squared} = .23$ ) for sagittal plane knee angle at MAX, with greater knee  
191 flexion at MAX observed during unopposed than opposed conditions (Table 1). This resulted  
192 in a significant effect for level of opposition (Wilks Lambda = .86,  $F = 9.61, p = .003,$   
193  $\text{partial eta squared} = .14$ ) for ROM of knee angle in the sagittal plane, with greater ROM of  
194 knee flexion observed during unopposed than opposed conditions (Table 1).

195 \_\_\_\_\_

196 Table 1 about here.

197 \_\_\_\_\_

198

199 \_\_\_\_\_

200 Figure 1 about here.

201 \_\_\_\_\_

202

203 In the frontal plane, there was no significant effect for level of opposition (Wilks  
204 Lambda = 1.00,  $F = .001, p = .97, \text{partial eta squared} = .001$ ) for the knee valgus angle at IC,  
205 no significant effect for level of opposition (Wilks Lambda = .95,  $F = 2.80, p = .10, \text{partial}$   
206  $\text{eta squared} = .05$ ) for MAX knee valgus angle and no significant effect for level of  
207 opposition (Wilks Lambda = .94,  $F = 4.05, p = .06, \text{partial eta squared} = .07$ ) for ROM of  
208 knee angle in the frontal plane (Table 1 and Figure 2).

209 \_\_\_\_\_  
210 Figure 2 about here.  
211 \_\_\_\_\_  
212

213 For most of the landing period, the normalized GRF was greater for opposed trials  
214 than unopposed trials (Figure 3). There was no significant effect for level of opposition  
215 (Wilks Lambada = .93,  $F = 2.17$ ,  $p = .15$ , partial eta squared = .07) for normalized GRF at  
216 MAX. For peak normalized GRF, there was a significant effect for level of opposition (Wilks  
217 Lambada = .93,  $F = 4.37$ ,  $p = .04$ , partial eta squared = .07) with greater normalized GRF  
218 observed during opposed conditions than unopposed conditions (Table 2).

219 \_\_\_\_\_  
220 Table 2 about here.  
221 \_\_\_\_\_  
222

223 \_\_\_\_\_  
224 Figure 3 about here.  
225 \_\_\_\_\_  
226

## 227 Effects of Gender

228 In the sagittal plane, there was no significant effect for gender ( $F = 3.65$ ,  $p = .06$ ,  
229 partial eta squared = .06) for knee flexion at IC. There was a significant effect for gender ( $F =$   
230  $13.3$ ,  $p = .01$ , partial eta squared = .19) for sagittal plane knee angle at MAX, with females  
231 displaying greater knee flexion at MAX than males (Table 1 and Figure 1). This resulted in a  
232 significant effect for gender ( $F = 14.7$ ,  $p = .001$ , partial eta squared = .20) for ROM of knee  
233 angle in the sagittal plane, with females displaying greater ROM of knee flexion than males  
234 (Table 1).

235 In the frontal plane, females tended to contact the ground with the knee in a valgus  
236 position (negative values for knee angle in the frontal plane) which progressively increased

237 between IC and MAX position. In contrast, males tended to contact the ground with the knee  
238 in a valgus position and moved into a varus position (positive values for knee angle in the  
239 frontal plane) at MAX (Table 1 and Figure 2). There was no significant effect for gender ( $F =$   
240  $.35, p = .56$ , partial eta squared = .01) for the knee valgus angle at IC. For MAX knee valgus  
241 angle, there was a significant effect for gender ( $F = 32.3, p = .001$ , partial eta squared = .36)  
242 with females exhibiting a greater MAX knee valgus angle than males (Table 1). This resulted  
243 in a significant effect for gender ( $F = 38.6, p = .001$ , partial eta squared = .40) for ROM of  
244 knee angle in the frontal plane, with females displaying a greater ROM of knee valgus angle  
245 than males (Table 1).

246 With regard to normalized GRF (Figure 3), the overall shapes of the curves were  
247 similar for males and females, where an increase was shown during approximately the first  
248 40% of the landing phase followed by decrease during approximately the final 60% of  
249 landing. For most of the landing period, the normalized GRF was greater for males than  
250 females. However, there was no significant effect for gender ( $F = .07, p = 0.79$ , partial eta  
251 squared = .02) for normalized GRF at MAX and no significant effect for gender ( $F = 1.43, p$   
252  $= .24$ , partial eta squared = .05) for peak normalized GRF (Table 2).

253

## 254 **Discussion**

### 255 Effects of Opposition

256 The results indicate significant differences in sagittal plane kinematics between  
257 unopposed and opposed trials. There was a significant effect for level of opposition in knee  
258 flexion at IC, with greater knee flexion at IC exhibited during unopposed conditions than  
259 opposed conditions. In addition, the effect for opposition was greater for females than males  
260 where females exhibited on average a  $4.4^\circ$  reduction in knee flexion at IC when opposition

261 was included in the task compared to a 0.9° reduction in males. ACL strain is likely to be  
262 increased with reduced knee flexion (Li et al., 1999; Nunley et al., 2003), therefore during  
263 unopposed trials participants may be more able to increase knee flexion at IC compared to  
264 opposed trials to reduce the likelihood of ACL strain. This may be due to participants having  
265 greater visual awareness of when ground contact is likely to take place during unopposed  
266 trials. Since participants did not need to spend as much time and attention watching the ball  
267 being spiked during unopposed trials, participants could anticipate ground contact more  
268 easily and therefore prepare for a safer landing through flexing the knee slightly before IC.  
269 There was a significant effect for level of opposition for MAX knee flexion and ROM of  
270 knee flexion, with greater knee flexion exhibited during unopposed conditions than opposed  
271 conditions. The results of the present study indicate values of maximum knee flexion  
272 measured during unopposed trials were nearer to values reported by previous studies where  
273 participants performed unopposed landing than those measured during opposed conditions.  
274 For example, mean maximum knee flexion of  $88.9^\circ \pm 11.4$  for males and  $78.3^\circ \pm 13.4$  for  
275 females were reported by Kernozek et al. (2005) compared to  $67.2^\circ \pm 12.9$  for males and  
276  $78.0^\circ \pm 8.1$  for females during unopposed trials and  $62.1^\circ \pm 11.6$  for males and  $68.2^\circ \pm 12.2$   
277 for females during opposed trials. The greater knee flexion exhibited during unopposed  
278 conditions compared to opposed conditions may be due to participants consciously increasing  
279 their knee flexion during unopposed trials in an attempt to reduce the impact of the GRF  
280 during landing and therefore reduce the risk of injury. However, during opposed trials, due to  
281 the greater attentional demand of effectively performing the blocking action, participants  
282 were, perhaps, less able to consciously increase the amount of knee flexion during landing.  
283 These results indicate that sagittal plane kinematics changed significantly with the  
284 introduction of opposition to the landing task and highlight the need for ecologically valid

285 task demands in studies designed to examine differences in the incidence of injuries between  
286 males and females in specific sports.

287         The results indicate no significant effect for level of opposition in knee valgus angle  
288 during landing. These results indicate that differences in frontal plane kinematics between  
289 males and females during landing were consistent between unopposed and opposed  
290 conditions. The values of maximum knee valgus angle reported in this study are different to  
291 previous results but as with the sagittal plane kinematics, the results of the present study  
292 indicate values of maximum knee valgus angle measured during unopposed trials were nearer  
293 to values reported by previous studies where participants performed unopposed landing than  
294 those measured during opposed conditions. For example, Ford et al. (2004) reported  
295 maximum knee valgus (-ve) / varus (+ve) angle values of  $-14.3^{\circ} \pm 2.0$  for males and  $-20.1^{\circ} \pm$   
296  $2.5$  for females, compared to  $-2.2^{\circ} \pm 5.3$  for males and  $-13.9^{\circ} \pm 11.3$  for females during  
297 unopposed trials and  $-2.9^{\circ} \pm 7.9$  for males and  $-10.4^{\circ} \pm 7.7$  for females during opposed trials  
298 in this study. There are a number of possible reasons for these differences which include  
299 participants' age and playing standard and the method of measuring the knee valgus angle. In  
300 Ford et al. (2004) the participants used were high school athletes whereas university athletes  
301 were used in this study. The valgus angle measured in Ford et al. (2004) was determined from  
302 markers placed on the skin over the greater trochanter, lateral epicondyle of the knee and the  
303 lateral malleolus of the ankle, whereas in this study, the valgus angle was based on estimated  
304 hip, knee and ankle joint centers using the Vicon plug-in gait model.

305         There was a significant effect for level of opposition in peak normalized GRF with  
306 greater normalized GRF exhibited during opposed conditions compared to unopposed  
307 conditions. When performing a landing from a jump, a participant is required to effectively  
308 reduce both their angular and linear momentum to zero. Having been stuck by the ball while  
309 in flight during the opposed trials, participants are likely to have a greater angular momentum

310 about their centre of gravity when they make contact with the ground during opposed trials  
311 than during unopposed trials. This means that participants must reduce a larger angular  
312 momentum, as well as their linear momentum, to zero during opposed trials. This greater  
313 momentum of the body at IC may contribute to greater GRF during opposed trials. Also, as  
314 stated previously, the reduced GRF during unopposed trials compared to opposed trials may  
315 be due to the greater ability of participants to consciously increase knee flexion during  
316 unopposed trials as a result of the reduced attentional demand of the task. This increased knee  
317 flexion may result in a reduction in the GRF acting on the body during landing and therefore  
318 reduce the likelihood of injury from high GRF.

319

#### 320 Effects of Gender

321 There was no significant effect for gender for knee flexion at IC, contrary to a number  
322 of previous studies (Decker et al., 2003; James et al., 2004; Yu et al., 2006). The values  
323 recorded in this study for knee flexion at IC are also slightly less than those reported in  
324 previous research. For example, Decker et al. (2003) reported knee flexion angles at IC of  
325  $30.0 \pm 7.7^\circ$  in males and  $22.8 \pm 8.0^\circ$  in females, compared to  $20.3 \pm 4.7^\circ$  for males and  $19.5 \pm$   
326  $6.9^\circ$  for females in the present study during unopposed trials. The reasons for this difference  
327 with the previous literature may be due to differences in the measuring systems and  
328 participants used since this study used experienced volleyball players whereas Decker et al.  
329 (2003) examined recreational athletes. Also, during unopposed trials there was a relatively  
330 small difference between males and females for knee flexion at IC (males  $0.8^\circ$  greater than  
331 females) whereas during opposed trials there was a larger gender difference (males  $4.3^\circ$   
332 greater than females). There was a significant effect for gender for MAX knee flexion and  
333 ROM of knee flexion, with greater knee flexion exhibited by females compared to males.  
334 Some previous studies have also found that females displayed greater knee flexion than males



335 during landing (Decker et al., 2003) whereas other found reduced knee flexion in females  
336 compared to males (Salci et al., 2004; Yu et al., 2006). In the present study, the greater knee  
337 flexion exhibited by females compared to males may be associated with the greater knee  
338 valgus shown by females than males, whereby females are less able to resist angular  
339 displacement on the knee during landing and therefore display reduced dynamic stability of  
340 the knee joint, which may be associated with ACL injury.

341         The results indicate significant differences in frontal plane kinematics between males  
342 and females. There was no significant effect for gender in knee valgus at IC, which is similar  
343 to the findings previous research (Kernozek et al., 2005). However, there was a significant  
344 effect for gender for MAX knee valgus and ROM of knee valgus, with females displaying  
345 greater knee valgus angle than males during landing. Greater knee valgus angle in females  
346 has also been found by a number of other studies examining frontal plane knee kinematics  
347 during unopposed landing tasks (Ford et al., 2003; Kernozek et al., 2005). Greater knee  
348 valgus angle during landing may indicate increased risk of ACL injury in females compared  
349 to males.

350         For most of the landing period, the normalized GRF was greater for males than  
351 females. This is contrary to a number of previous studies examining gender differences in  
352 normalized GRF during landing (Kernozek et al., 2005; Salci et al., 2004; Yu et al., 2006).  
353 The difference in the findings of the present study and previous studies is likely to be due to  
354 differences in task demands participants were required to perform. Typically, previous  
355 studies have examined drop-jump landings from the same set height for males and females  
356 whereas the present study examined a sport specific volleyball block jump landing, where  
357 males and females were more likely to land from a jump height typical of what they are likely  
358 to perform during their sport.

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

369

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471 **Author Notes**

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474 Corresponding Author: Dr. Gerwyn Hughes.

475 Postal Address: Division of Sport, Health and Exercise, University of Hertfordshire,  
476 College Lane, Hatfield, AL10 9AB.

477 Email: g.hughes@herts.ac.uk

478 Telephone: + 44 1707289430

479

480 Author 2: Prof. James Watkins.

481 Postal Address: Department of Sports Science, Swansea University, Singleton Park,  
482 Swansea, SA2 8PP.

483 Email: j.watkins@swansea.ac.uk

484

485 Author 3: Mr. Nick Owen.

486 Postal Address: Department of Sports Science, Swansea University, Singleton Park,  
487 Swansea, SA2 8PP.

488 Email: n.owen@swansea.ac.uk

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491 **Tables**

492

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

		Males		Females	
		Unopposed (°)	Opposed (°)	Unopposed (°)	Opposed (°)
	IC *	20.3 ± 4.7	19.4 ± 6.4	19.5 ± 6.9	15.1 ± 6.2
Flexion	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
	IC	-2.2 ± 5.3	-2.8 ± 5.9	-2.1 ± 3.4	-1.6 ± 2.8
Val/var	MAX <sub>VAL</sub> †	-2.2 ± 5.3	-2.9 ± 7.9	-13.9 ± 11.3	-10.4 ± 7.7
	MAX <sub>VAR</sub>	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

496

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

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

499

500 Table 2. Group mean results for normalized GRF at MAX and peak (Mean  $\pm$  standard  
501 deviation).

		<b>MAX GRF (BW)</b>	<b>Peak GRF (BW)</b>
Males	Unopposed	0.752 $\pm$ 0.194	1.561 $\pm$ 0.663*
	Opposed	0.972 $\pm$ 0.415	1.861 $\pm$ 0.595*
Females	Unopposed	0.873 $\pm$ 0.210	1.457 $\pm$ 0.477*
	Opposed	0.894 $\pm$ 0.378	1.631 $\pm$ 0.427*

502

503 \*: Significant effect between unopposed and opposed trials.

504

505 **Figure Captions**

506

507 Figure 1. Knee flexion ( $\theta_f$ ) between IC and MAX for males and females during unopposed  
508 and opposed trials.

509 Figure 2. Knee valgus/varus ( $\theta_v$ ) between IC and MAX for males and females during  
510 unopposed and opposed trials.

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

513