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1 **Abstract**

2 *Context:* Anterior Cruciate Ligament (ACL) and Patellofemoral Joint (PFJ) injuries are a
3 significant problem among female athletes. A number of screening tasks have been used in the
4 literature to identify those at greatest risk of injury. To date, no study has examined the
5 relationship in two-dimensional (2D) knee valgus between common screening tasks to
6 determine whether individuals exhibit similar movement patterns across tasks.

7 *Objective:* to establish whether frontal plane projection angle (FPPA) during the single leg
8 squat (SLS), single leg land (SLL) and drop jump (DJ) are related

9 *Design:* Cross-sectional Study

10 *Setting:* University Laboratory

11 *Participants:* 52 national league female football players and 36 national league female
12 basketball players

13 *Main Outcome Measures:* 2D FPPA during the SLS, SLL and DJ screening tasks

14 *Results:* Significant correlations were found between tasks. FPPA in the SLS was significantly
15 correlated with SLL ($r = 0.52$) and DJ ($r = 0.30$), whilst FPPA in the SLL was also significantly
16 correlated to DJ ($r = 0.33$). FPPA was significantly greater in the SLS compared to the SLL
17 ($p < 0.001$) and DJ ($p < 0.001$) and in the SLL compared to the DJ ($p < 0.001$).

18 *Conclusions:* Our results showed that 2D FPPA is correlated across the SLS, SLL and DJ tasks.
19 However, significantly greater FPPA values in the unilateral tasks suggest that the DJ may not
20 identify risk of injury in sports primary injury mechanisms are during unilateral loading tasks.
21 Therefore it is recommended that both unilateral and bilateral tasks are included when
22 screening for ACL and PFJ injury risk.

23

24

25

26 **Introduction**

27 A high prevalence of anterior cruciate ligament (ACL) and patellofemoral joint (PFJ) injuries
28 in soccer and basketball players has been widely reported, with females typically at least two
29 times more likely to suffer an ACL or PFJ injury than males ^[1-3]. Poor alignment of the lower
30 limb, specifically increased knee valgus, during the drop jump (DJ) screening task has been
31 prospectively associated with ACL and PFJ injury in female athletes ^[4, 5].

32
33 The DJ task is often the only test used in research and clinical environments to screen for ACL
34 and PFJ injury risk due to the association between injury risk and poor neuromuscular control.
35 Whilst this may be appropriate for sports where landing is the primary injury mechanism, this
36 may fail to identify athletes at risk of injury in sports such as soccer, where the majority of
37 injuries occur during single leg cutting and pivoting tasks ^[6]. In such cases the DJ task does not
38 necessarily replicate this mechanism of injury and may therefore limit the ability to fully
39 understand injury risk. Harty et al. ^[7] have shown that correlations exist between knee valgus
40 angles and moments across the step-down, SLL and DJ tasks. In contrast however, Kristianlund
41 and Krosshaug ^[8] found that significant correlations were evident between knee valgus angles
42 in DJ and cutting tasks but not for knee valgus moments. These results underline the possible
43 limitations of using a single task when screening for knee injury risk in sports such as soccer.

44
45 A unilateral task may be more appropriate for identifying ACL injury risk in sports such as
46 soccer and basketball. Recently, Jones et al. ^[9] reported correlations between knee valgus
47 angles and moments in single leg landing (SLL), cutting and pivoting tasks in female soccer
48 players. These results suggest that those players who exhibit poor lower limb biomechanics in
49 the SLL are likely to do so in change of direction tasks, which may increase their risk of ACL
50 and PFJ injury. Whatman et al. ^[10] suggested that the kinematics demonstrated during a single

51 leg squat (SLS) was a useful screening tool to assess an individual's lower limb dynamic
52 alignment and potential injury risk due to strong correlation with knee valgus during jogging.
53 This was further supported by Alenzi et al. ^[11] who found significant correlations in knee valgus
54 angles between the SLS and running and cutting tasks.

55

56 Each of the studies mentioned above have utilised 3-dimensional (3D) analysis to determine
57 motion of the lower limb. However, the limited availability of 3-dimensional (3D) analysis in
58 clinical practice due to financial, spatial and temporal costs has led to the development of 2-
59 dimensional (2D) techniques, which employ less expensive, portable and easy to use
60 equipment. 2D analysis, more specifically frontal plane projection angle (FPPA), has been
61 shown to be a valid and reliable method to quantify knee valgus motion during a number of
62 screening tasks, including the SLS, SLL, DJ, side-step and side jump ^[12-14]. A small preliminary
63 study of 15 recreational athletes found significant correlations in FPPA between the SLS, SLL
64 and running in women but not men ^[15], although the small sample means that further
65 investigation with a larger sample is warranted.

66

67 To date, no study has fully examined the relationship in FPPA between common screening
68 tasks to determine whether individuals exhibit similar FPPA values across tasks. Therefore the
69 aim of this study is to establish whether FPPA during the SLS, SLL and DJ are related. Based
70 on previous research, we hypothesised that FPPA in each task would be related, but that there
71 would be a greater FPPA in the SLL land due to the higher velocity of movement compared to
72 the SLS and the greater loading due to the unilateral nature compared to the DJ.

73

74 **Methods**

75 *Participants*

76 52 national league female football players (age 19.3 ± 4 years, height 1.61 ± 0.6 m, weight 60 ± 8.5
77 kg) and 36 national league female basketball players (age 22.1 ± 3.8 years, height 1.71 ± 0.6
78 m, weight 69.4 ± 11.3 kg) undertook testing on one occasion. All participants were involved in
79 the sports on a part-time basis and participated in training and competition \geq three times per
80 week. All participants were free from lower extremity injury, defined as any complaint which
81 stopped the participant from undertaking their normal exercise routine, for at least 3 months
82 prior to data collection. Written informed consent was obtained from all participants, in the
83 case of those between 16 and 18 years of age from a parent or guardian, and the project was
84 approved by the University's research and ethics committee.

85

86 *Procedures*

87 Prior to testing, markers were placed on the lower extremity of each subject to approximate the
88 radiographic landmarks employed by Willson et al. ^[16] and Willson and Davis ^[12]. Markers
89 were placed at the midpoint of the femoral condyles to approximate the centre of the knee joint,
90 midpoint of the ankle malleoli for the centre of the ankle joint, and on the proximal thigh along
91 a line from the anterior superior iliac spine to the knee marker. The midpoints were determined
92 using a standard tape measure and all markers were placed by the same experimenter. These
93 markers were used in order for FPPA of the knee to be determined from digital images using
94 Quintic software package (version 26). A single experimenter digitised the markers placed on
95 the subject, allowing FPPA of the knee to be obtained.

96

97 A digital video camera (Sony Handycam DCR-HC37) recording at 30fps was placed at a height
98 of 50cm, 3m anterior to the participants landing target. All participants were asked to perform

99 3 common screening tasks; the single leg squat, single leg drop landing and bilateral drop jump.
100 Each participant was given the opportunity to practice the tasks until they were comfortable,
101 this was typically 2 practice trials. Participants were then asked to perform 3 test trials for each
102 task with their mean performance being used for later analysis; the sequence of tasks was
103 assigned in block order. Both legs were tested. Reliability of the methods has previously been
104 shown ^[14].

105

106 Single leg squat test (SLS) task

107 Participants were asked to stand on the test limb, facing the video camera. Participants were
108 asked to squat down as far as possible, to at least 45° knee flexion, over a period of 5 seconds.
109 Knee flexion angle was checked during practice trials using a standard goniometer (Gaiam-
110 Pro) **then observed by the same examiner throughout the trials**. There was also a counter for
111 each participant over this 5 second period in which the first count initiates the movement, the
112 third indicates the lowest point of the squat and the fifth indicates the end. This standardises
113 the test for each participant, therefore reducing the effect of velocity on knee angles. Trials
114 were only accepted if the subject squats to the minimum desired degrees of knee flexion and
115 they maintain their balance throughout.

116

117 Drop Jump (DJ) task

118 Participants stood with feet shoulder width apart on a 28 cm high step, 30 cm from the landing
119 target. Participants were instructed to lean forward and drop from the step as vertically as
120 possible, in an attempt to standardize landing height ^[17]. Upon landing, participants were
121 required to immediately perform a maximal vertical jump, finally landing back on the landing
122 target. There were no set instructions regarding arm movement, only for the participants to

123 perform the jump naturally and the initial landing from the step was used for analysis purposes
124 ^[18].

125

126 Single leg landing (SLL) task

127 As with the drop jump task participants dropped from a 28 cm step, again leaning forward and
128 dropping as vertically as possible. Participants were asked to take a unilateral stance on the
129 contralateral limb and to step forward to drop onto the landing target, ensuring the contralateral
130 leg made no contact with any other surface.^[18]

131

132 FPPA

133 FPPA of the knee was measured as the angle subtended between the line from the markers on
134 the proximal thigh to the knee joint and the line from the knee joint to the ankle ^[16] and was
135 measured at the frame which corresponded with the point of maximum knee flexion, as shown
136 in figure 1. **The point of maximum knee flexion was determined as the lowest point of the squat
137 and landing tasks as observed on the video.** Positive FPPA values reflected knee valgus,
138 excursion of the knee towards the midline of the body so that the knee marker was medial to
139 the line between the ankle and thigh markers, whilst negative FPPA values reflected knee
140 varus.

141

142 *Statistical Analyses*

143 All statistical analyses were performed in SPSS for Windows version 17 (SPSS Inc., Chicago,
144 IL). Normality for each variable was inspected using the Shapiro-Wilk test. Within-session
145 reliability was calculated using Intraclass Correlation Coefficient (ICC_{3,1}) and interpreted
146 according to the criteria set by Coppieters et al. ^[19]. Pearson correlation coefficient and
147 coefficient of determination were used to explore relationships between FPPA in the 3

148 screening tasks. A repeated-measures ANOVA with Bonferonni post-hoc analysis was used to
149 determine whether any significant differences in FPPA were evident between tasks. Effect sizes
150 were also calculated to determine the magnitude of any differences between screening tasks
151 and interpreted based on the recommendations of Rhea ^[20] where <0.35, 0.35-0.80, 0.80-1.50
152 and >1.5 are trivial, small, moderate and large, respectively. Statistical significance was set at
153 $p < 0.05$.

154

155 **Results**

156 All variables were found to be normally distributed ($p > 0.05$). Within-session reliability was
157 good to excellent (ICC 0.89-0.92). The results of the repeated-measures ANOVA (figure 2)
158 showed that FPPA was significantly greater in the SLS ($9.72 \pm 6.04^\circ$) compared to the SLL
159 ($7.63 \pm 6.40^\circ$, $d = 0.34$, $p < 0.001$) and DJ ($0.67 \pm 9.65^\circ$, $d = 1.12$, $p < 0.001$) and in the SLL
160 compared to the DJ ($d = 0.85$, $p < 0.001$).

161

162 Significant correlations were also evident between each of the tasks (figures 3a-c). FPPA in
163 the SLS was significantly correlated with SLL ($r = 0.52$, $r^2 = 27\%$) and DJ ($r = 0.30$, $r^2 = 9\%$),
164 whilst FPPA in the SLL was also significantly correlated to DJ ($r = 0.33$, $r^2 = 11\%$).

165

166 **Discussion**

167 The results of the current study supported the hypothesis that FPPA would be related across
168 the SLS, SLL and DJ tasks. Previous research has shown that relationships exist for 3D knee
169 valgus motion in the step-down, SLL and DJ tasks ^[7]; DJ and cutting ^[8]; SLL and cutting ^[9];
170 and jogging with the SLS, squat, lunge, hop-lunge and step-down ^[10]. However, it was unclear
171 from the previous literature whether these associations would be evident using 2D motion
172 analysis.

173

174 Our results showed a strong relationship between FPPA in the SLS and SLL ($r = 0.52$) and
175 moderate relationship between the SLS and DJ ($r = 0.30$). The relationship between SLS and
176 SLL supports the findings of the preliminary study on by Atkin et al. ^[15], albeit the strength of
177 the correlation is weaker in the current study. Atkin et al. only studied eight women and
178 therefore the stronger correlations may not represent those of the larger population. In addition,
179 they studied recreational athletes, whose biomechanics may differ to the female athletes in the
180 current study. Considering that strong correlations in 3D knee valgus angles have previously
181 been shown between the SLS and jogging and cutting ^[10, 11], this suggests that dynamic knee
182 valgus motion during the SLS task is likely to be exhibited across more dynamic tasks.
183 Furthermore, Atkin et al. ^[15] have shown a relationship in women between 2D FPPA in the
184 SLS and running which demonstrates the potential clinical utility of 2D FPPA to screen female
185 athletes using a simple SLS test.

186

187 Previous research by Jones et al. ^[9] found strong correlations for knee valgus angles and
188 moments between the single leg landing (SLL), cutting and pivoting tasks in female soccer
189 players. In the current study the SLL task also showed a moderate correlation to the DJ ($r =$
190 0.33) which was greater than the correlation between the SLS and DJ tasks. Considering that
191 knee valgus motion during the DJ task has been shown to predict ACL and PFJ injury and that
192 ACL injury often occurs during cutting and pivoting manoeuvres, the SLL task may be a more
193 useful screening tool than the SLS for individuals participating in sport.

194

195 Although Kristianlund and Krosshaug ^[8] found the relationship between DJ and cutting were
196 evident for knee valgus angles, they noted that no relationships existed for knee valgus
197 moments. The lack of relationship in valgus moments between the tasks highlights the potential

198 drawback of using a single screening task to identify injury risk, particularly in sports where
199 the majority of ACL injuries occur during single leg cutting and pivoting tasks. Whilst the DJ
200 task has been shown to predict ACL injury, the ability to fully understand injury risk may be
201 limited by the use of the DJ task alone as it does not replicate the often unilateral mechanism
202 of injury. The moderate relationships found between the tasks along with the significantly
203 greater FPPA values in the SLS and SLL tasks in the current study, highlight the potential
204 difference between unilateral and bilateral tasks. Furthermore, the strong correlations for knee
205 valgus angles and moments between the single leg landing (SLL), cutting and pivoting tasks
206 found by Jones et al. suggest that the inclusion of a unilateral screening task alongside the DJ
207 should be considered in future prospective studies to determine their efficacy for ACL injury
208 risk screening.

209

210 We also hypothesised that FPPA would be greatest in the SLL land due to the higher velocity
211 of movement compared to the SLS and the greater loading due to the unilateral nature
212 compared to the DJ. This in part was correct; the SLL resulted in greater FPPA values than the
213 DJ. However, we also found that FPPA was slightly greater in the SLS compared to the SLL,
214 a result which was unexpected; although the effect sizes demonstrated that the magnitude of
215 differences was trivial. This result is supported by a previous study we conducted with
216 recreational men and women where, although no statistical tests were undertaken, SLS FPPA
217 was around 4° greater than SLL ^[14].

218

219 The greater FPPA during the SLS may be explained by a lack of familiarity with the task being
220 executed. Soccer and basketball players commonly perform bilateral and unilateral landing
221 manoeuvres within their sporting and training performance, whereas they rarely perform a
222 unilateral squat. Therefore, their relatively better performance in the SLL and DJ tasks

223 compared to the SLS may be due to the effect of skill acquisition. A recent study by Herrington
224 et al. [21] found that changes in FPPA in specific tasks may be attributed to the type of training
225 undertaken. They found that participants who underwent 6 weeks of jump-landing training
226 showed significant improvement in SLL and DJ FPPA, whilst those who undertook strength
227 training improved their SLS and SLL scores. Participants who completed the jump-landing
228 training were continuously practicing unilateral and bilateral plyometric techniques whilst the
229 strength training programme including bilateral and unilateral squatting tasks. The authors
230 argued that the changes observed were likely a result of the type of training and tasks
231 undertaken during the training programme.

232

233 The findings are limited to women who participate in soccer and basketball and cannot be
234 attributed to the wider population, although similar findings have been noted in recreationally
235 active women. Whilst our results indicate that injury risk screening should utilise both bilateral
236 and unilateral tasks, caution should be exercised as no study has yet shown that 2D screening
237 tests prospectively identify athletes at risk of ACL or PFJ, therefore further research is
238 warranted. **It is not clear whether the frontal plane estimation of maximum knee flexion angle
239 used in this study is accurate, therefore future studies should consider the inclusion of a camera
240 in the sagittal plane to ensure the correct frame is analysed.**

241

242 **Conclusion**

243 In line with previous research using 3D motion analysis, our results showed that 2D FPPA is
244 correlated across the SLS, SLL and DJ tasks. However, significantly greater FPPA values in
245 the unilateral tasks suggest the ability of the DJ to identify those who are at risk of injury in
246 sports where injury mechanism is mainly during unilateral loading tasks may be limited.
247 Therefore it is recommended that both unilateral and bilateral tasks are included when

248 screening for ACL and PFJ injury risk to gain a more complete understanding of an individual's
249 movement strategies and potential injury risk.

250

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