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Title: Knee joint position sense ability in elite athletes who have returned to international level play following ACL reconstruction: A cross-sectional study.

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**Abstract: Background and Objectives:** Following an ACL injury, reconstruction (ACL-R) and rehabilitation athletes may return to play with a proprioceptive deficit. However, literature is lacking to support this hypothesis in elite athletic groups who have returned to international levels of performance. It is possible the potentially heightened proprioceptive ability evidenced in athletes may negate a deficit following injury. The purpose of this study was to consider the effects ACL injury, reconstruction and rehabilitation on knee joint position sense (JPS) on a group of elite athletes who had returned to international performance. **Methods:** Using a cross-sectional design ten elite athletes with ACL-R and ten controls were evaluated. JPS was tested into knee extension and flexion using absolute error scores. Average data with 95% confidence intervals between the reconstructed, contralateral and uninjured control knees were analysed using t-tests and effect sizes. **Results:** The reconstructed knee of the injured group demonstrated a significantly greater angle of error score when compared to both the contralateral and uninjured control knees into knee flexion ( $p=0.0001$ ,  $r=0.98$ ) and knee extension ( $p=0.0001$ ,  $r=0.91$ ). There were no significant differences between the contralateral uninjured knee of the injured group and the uninjured control group. **Conclusions:** Elite athletes who have had an ACL injury, reconstruction, rehabilitation and returned to international play demonstrate lower JPS ability compared to control groups. It is unclear if this deficiency affects long-term performance or secondary injury and re-injury problems. In the future physical therapists should monitor athletes longitudinally when they return to play.

Reviewers' comments:

AE: Can you make this small addition

Reviewer #2: Thank you for considering my comments and suggestions. The authors have made substantial improvements to the manuscript. The only comment I have is that I wish them to include a sentence to the method that reads "No association between time since reconstruction and JPS was found,  $p>0.05$ " or similar.

RESPONSE: Many thanks for your comments. We have added a paragraph to the results section (lines 131 – 137) to ensure the reader is aware there is no relationship between time since surgery and JPS ability. We hope this is satisfactory.

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Monday 15<sup>th</sup> August 2016

Dear Dr Al-Dadah and Dr Hing,

Please find attached our revised original research paper entitled “Knee joint position sense ability in elite athletes who have returned to international level play following ACL reconstruction: A cross-sectional study”. I can confirm no part of this work has been duplicated in any other publication. There are no commercial relationships which may lead to conflicts of interest. I can also confirm the typescript has been read and agreed by the other author; Lee Herrington, School of Health Sciences, University of Salford, Salford, M6 6PU, [L.C.Herrington@Salford.ac.uk](mailto:L.C.Herrington@Salford.ac.uk). I can confirm that all authors were fully involved in the study and preparation of the manuscript and that the material within has not been and will not be submitted for publication elsewhere.

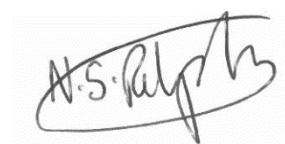
Yours Faithfully,

A handwritten signature in black ink, appearing to read "N.S. Relph", enclosed within a hand-drawn oval.

Dr Nicola Relph

Declaration of Interest

The authors report no declarations of interest.

A handwritten signature in black ink, enclosed in a hand-drawn oval. The signature appears to read "N.S. Relph" followed by a stylized flourish.

Dr Nicola Relph

## Abstract

**Background and Objectives:** Following an ACL injury, reconstruction (ACL-R) and rehabilitation athletes may return to play with a proprioceptive deficit. However, literature is lacking to support this hypothesis in elite athletic groups who have returned to international levels of performance. It is possible the potentially heightened proprioceptive ability evidenced in athletes may negate a deficit following injury. The purpose of this study was to consider the effects ACL injury, reconstruction and rehabilitation on knee joint position sense (JPS) on a group of elite athletes who had returned to international performance. **Methods:** Using a cross-sectional design ten elite athletes with ACL-R and ten controls were evaluated. JPS was tested into knee extension and flexion using absolute error scores. Average data with 95% confidence intervals between the reconstructed, contralateral and uninjured control knees were analysed using t-tests and effect sizes. **Results:** The reconstructed knee of the injured group demonstrated a significantly greater angle of error score when compared to both the contralateral and uninjured control knees into knee flexion ( $p=0.0001$ ,  $r=0.98$ ) and knee extension ( $p=0.0001$ ,  $r=0.91$ ). There were no significant differences between the contralateral uninjured knee of the injured group and the uninjured control group. **Conclusions:** Elite athletes who have had an ACL injury, reconstruction, rehabilitation and returned to international play demonstrate lower JPS ability compared to control groups. It is unclear if this deficiency affects long-term performance or secondary injury and re-injury problems. In the future physical therapists should monitor athletes longitudinally when they return to play.

**Keywords:** Elite sport; proprioception; knee injury.

1 Knee joint position sense ability in elite athletes who have returned to international level play  
2 following ACL reconstruction: A cross-sectional study.

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## 20 **Introduction**

21 The anterior cruciate ligament (ACL) is the most commonly injured knee ligament with an  
22 estimated 6.5 injuries per 10,000 athletic exposures (Bien and Dubuque, 2015).  
23 Mechanoreceptors located in the native ACL provide important information on the position,  
24 movement and force of the knee joint (Johansson *et al.*, 2000; Riemann & Lephart, 2002;  
25 Schultz *et al.*, 1984), this is known as proprioception (Lephart *et al.*, 1996). Therefore, ACL  
26 injury may impair proprioception through disruption to the transmission of this sensory  
27 information (Barrack & Munn, 2000; Relph *et al.*, 2014). Up to 90% of ACL injured patients  
28 in the United States opt for surgical reconstruction of the damaged ligament (Bien and  
29 Dubuque, 2015). It is unclear whether following this surgery proprioceptive ability in elite  
30 athletes is improved (Muaidi *et al.*, 2009a, Reider *et al.*, 2003, Angoules *et al.*, 2011) or  
31 remains at the post injury level (Dhillon *et al.*, 2011).

32 Uninjured elite athletes may have heightened joint position sense (JPS) (a measure of static  
33 proprioceptive accuracy) compared to healthy but non-specialised sporting controls due to  
34 extended athletic training and/ or innate capabilities that provide enhanced mechanoreceptor  
35 sensitivity (Han *et al.*, 2014, Ashton-Miller *et al.*, 2001). Athletes participating in National or  
36 International gymnastics, dance, American football, swimming, dancing and archery have  
37 heightened knee JPS ability compared to non-athletic controls (Euzet and Gahery 1995, Han  
38 *et al.*, 2015, Waddington *et al.*, 2013). Olympic level soccer players also have better joint  
39 position sense acuity than non-athletic controls (Muaidi *et al.*, 2009b). Therefore athletes may  
40 be a population of interest for the clinical practitioner. However, we suspect that the generally  
41 heightened JPS seen in athletes may be impaired after ACL injury and reconstruction, even as  
42 they return to high-level play. But is not well known to what extend this deficiency is present  
43 at international level athletes and if the potentially heightened JPS in elite athletes negates the  
44 deficiency in any way following injury and rehabilitation. It is plausible that extended

45 training and innate characteristics of this special population compensate for the effects of  
46 ACL injury.

47 There is only limited evidence on knee JPS in athletic specific populations following knee  
48 injury. Ribeiro and Costa (2001) compared the JPS of knee injured athletes to uninjured  
49 surfers and uninjured controls; the injured group produced the highest joint positioning errors  
50 and hence the lowest ability to detect knee joint position. However, groups were small (five  
51 or four) and the study lacked statistical power. Furthermore, no detail of the injuries or sports  
52 of the injured group were provided. Conversely, Naseri and Pourkazemi (2012) investigated  
53 the effect of patellofemoral pain on knee JPS in University level athletes and reported no  
54 differences between injured athletes and uninjured athletes which suggests the injury in  
55 athletes may not reduce proprioceptive ability. However, to the authors' knowledge there has  
56 been no research on elite athletes' knee JPS ability following an ACL reconstruction and  
57 return to international sport.

## 58 **Purpose and hypothesis**

59 There is a lack of research investigating knee proprioception ability after an ACL injury,  
60 reconstruction and rehabilitation before return to sport on elite athletes. Therefore it unclear if  
61 the potential increased proprioception ability in this population remains. The purpose of this  
62 study is to consider knee joint position sense ability in elite athletes who have returned to  
63 international level play following ACL reconstruction.

## 64 **Materials and methods**

### 65 **Patient selection**

66 Ten elite athletes (three male, seven female; age  $22.4 \pm 3.75$  years; three taekwondo  
67 competitors, three footballers, two netballers, one middle distance runner, one judo



68 competitor) who had all undergone ACL reconstructive surgery ( $17.9\pm 4.68$  months since  
69 surgery; type of reconstruction; six hamstring, four bone-patellar tendon bone) took part in  
70 the study and were recruited using purposive sampling. All had returned to playing elite level  
71 sport ( $6.2\pm 0.63$  months since return to play; Lysholm score  $94.2\pm 1.69$ ) at either a junior  
72 international ( $n=5$ ) or senior international ( $n=5$ ) level. All injured athletes had followed a  
73 criterion based rehabilitation programme as described in Herrington *et al.*, (2012) and were  
74 not currently participating in any sensorimotor training. Ten healthy active participants (three  
75 male, seven female; age  $22.1\pm 4.07$  years; Lysholm  $100\pm 0$ ) acted as age, gender and sport  
76 matched controls. The controls were matched in this way as previous literature has suggested  
77 knee JPS may be influenced by such variables (Aydoğ *et al.*, 2006; Nagai *et al.*, 2012;  
78 Shaffer & Harrison, 2007). All participants were free from current lower extremity injury and  
79 any chronic disease that may affect proprioception such as visual or vestibular function,  
80 peripheral neuropathy and diabetes mellitus (Arockiaraj *et al.*, 2013). Participants read an  
81 information sheet and provided written informed consent. This study was approved by the  
82 University ethics board (REP10/068).

83 Participants wore shorts and removed their socks and shoes. The participants were prepared  
84 for data collection by placing markers on the following anatomical points; a point on a line  
85 following the greater trochanter to the lateral epicondyle close to the lateral epicondyle  
86 (placement of a marker directly on the greater trochanter is difficult due to clothing), the  
87 lateral epicondyle and the lateral malleolus of both legs. The procedure was previously  
88 validated against an isokinetic dynamometer protocol (Relph & Herrington, 2015b). The  
89 intra-class correlation coefficients (ICC) value corresponding to inter-examiner reliability of  
90 the technique was 0.98 and Cronbach's Alpha was 0.99 in a previous study using identical  
91 procedures. Furthermore, the ICC value for intra-examiner reliability was 0.96 and  
92 Cronbach's Alpha was 0.98. Test-retest reliability has also been reported in a previous work

93 as large for both knee flexion (ICC = 0.92) and knee extension (ICC = 0.86) procedures  
94 (Relph & Herrington, 2015a). The standard error of the measurement (SEM) was 0.40° and  
95 0.60° for knee flexion and knee extension respectively (Relph & Herrington, 2015a). The  
96 smallest detectable difference (SDD) was 1.10° for knee flexion and 1.35° for knee extension  
97 measurements (Relph & Herrington, 2015a). This is an important addition to knee JPS  
98 research as previous studies have failed to adequately test the reliability of measurements  
99 before use (Beynnon *et al.*, 2000; Relph *et al.*, 2014; Ozenci *et al.*, 2007; Gokeler *et al.*,  
100 2012).

101 The participant was seated on the end of a physiotherapy plinth and blindfolded. The leg was  
102 passively moved by the experimenter through 30°-60° of extension from a starting knee angle  
103 of 90° or through 60°-90° of flexion from a starting angle of 0° to a target angle in the  
104 specified range at an approximate angular velocity of 10°/s. The researcher used a visual  
105 goniometer to estimate the angular velocity and ensure the target position was located in the  
106 correct range (see Figure 1). The participant then actively held the leg in the target position  
107 for five seconds. During this time, a photograph of the leg in the target position (see Figure 1)  
108 was taken using a standard camera (Casio Exilim, EX-FC100, Casio Electronics Co., Ltd.  
109 London, UK) placed three metres from the sagittal plane of movement on a fixed level tripod  
110 (Camlink TP-2800, Camlink UK, Leicester, UK). The leg was then passively returned to the  
111 starting angle by the researcher and the participant was instructed to actively move back to  
112 the target angle. Another photograph was taken and the participant instructed to move their  
113 leg back to the starting position. The process was repeated five times for each target angle on  
114 the injured and uninjured leg of the ACL group and the dominant leg of the control group.

115

116 **Data Analysis**

117 Knee angles were measured using two-dimensional manual digitising software (ImageJ, U.S.  
118 National Institutes of Health,, Maryland, USA, <http://imagej.nih.gov/ij/>, 1997-2012). Knee  
119 joint position sense ability was calculated from the average difference between target and  
120 reproduction angles across five flexion and five extension trials producing absolute error  
121 scores. Means, standard deviations and 95% confidence intervals were presented.

122 All statistical analyses was completed in SPSS (Version 19, IBM Corporation, New York,  
123 USA). The Kolmogorov-Smirnov test was used to examine normality of data, which was  
124 confirmed. Significant differences between the injured and uninjured knees of the ACL group  
125 were tested using a dependent (paired) t-test with an alpha level set at  $p < 0.05$ . Significant  
126 difference between the injured or uninjured knees of the ACL group and the knee of the  
127 control group were tested using independent t-tests with an alpha level set at  $p < 0.05$ . Effect  
128 sizes were also calculated using the following equation –

129

$$130 \quad r = \sqrt{\frac{t^2}{t^2 + df}} \quad (\text{Field, 2014, p.376})$$

131 where  $t$  is the  $t$  statistic and  $df$  is the degrees of freedom.

132

### 133 **Results**

134 To ensure there was no association between time since surgery and JPS ability of the ACLR  
135 group, Pearson's correlation coefficient analyses were completed. There was no association  
136 between time since reconstructive surgery and JPS ability of the injured knee into flexion  
137 ( $p=0.472$ ) or extension ( $p=0.120$ ). There were also no association between time since  
138 reconstructive surgery and JPS ability of the uninjured knee into flexion ( $p= 0.719$ ) or  
139 extension ( $p=0.557$ ). Therefore, time since reconstructive surgery (average  $17.9 \pm 4.68$  months  
140 since surgery) has no relationship to JPS ability in this sample.

141 Tables one and two display the JPS differences between the ACLR knees, contralateral knees  
142 and the uninjured control group knees. The ACLR knees had on average a greater mean error  
143 score by 4.6° and hence lower joint position sense ability in knee flexion when compared to  
144 their contralateral knees. The ACLR knees also had on average 5° more error than the  
145 uninjured control group. This finding was repeated in knee extension JPS; ACLR knees had  
146 poorer JPS compared to the contralateral side (difference of 5.3°) and uninjured controls  
147 (difference of 4.4°). In addition, the contralateral knees displayed similar JPS ability to  
148 uninjured control knees for both knee flexion ( $p=0.555$ ) and knee extension ( $p=0.187$ ).

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TABLE 1 AND 2 NEAR HERE

## 152 **Discussion**

153 The purpose of this study was to consider knee joint position sense ability in elite athletes  
154 who have returned to international level play following ACL injury, reconstruction and  
155 rehabilitation. The results indicate that the athletes demonstrated reduced static  
156 proprioceptive ability, despite having successfully completed a structured rehabilitation  
157 programme and retuning to play. This effect was evident in comparison to both the  
158 contralateral knee and an uninjured control knee and into knee flexion and extension.

159 There is no specific research on the knee JPS of elite athletic populations returning to  
160 international level performance following an ACL injury to support these findings. However,  
161 there is substantial evidence to support these findings in non-athletic populations (Relph *et al.*  
162 *al.*, 2014, Angoules *et al.*, 2011, Katayama *et al.*, 2004, Baumeister *et al.*, 2008). Results of a  
163 meta-analysis reported significantly greater knee JPS error scores in ACL reconstructed  
164 patients compared to both the contralateral leg and uninjured controls (Relph *et al.*, 2014).  
165 Previous literature implies mechanoreceptors in the ACL provide afferent important

166 information on the relative position and movement of the knee joint (Riemann and Lephart  
167 2002, Johansson *et al.*, 2000, Schultz *et al.*, 1984). Therefore, ACL injury appears to impair  
168 proprioceptive ability through disruption of the transmission of this sensory information  
169 (Barrack and Munn, 2000). Marks *et al.*, (2007) suggest this disrupted afferent information to  
170 the central nervous system consequently reduces joint position sense ability, this may explain  
171 the increased error scores in the current study. A history of elite level participation does not  
172 appear to negate the proprioceptive deficit following reconstructive surgery.

173 The error scores in the athletic injured knee were on average 5° greater into knee flexion and  
174 5.3° greater into knee extension than the uninjured knee and control group. These values are  
175 above the reported SDDs of 1.10° for knee flexion and 1.35° for knee extension for this  
176 protocol (Relph & Herrington, 2015a). Callaghan *et al.*, (2002) and Burgess *et al.*, (1982)  
177 suggest that a “*poor*” and potentially clinically relevant error score corresponds to a score  
178 greater than 5° using similar techniques. Therefore practitioners should be aware that even  
179 ACL reconstructed elite athletes may still have clinically relevant proprioception deficits  
180 even when returning to play.

181 Importantly, the injured athletes in this study had all returned to international level sport  
182 participation, suggesting the reduction in knee JPS ability may not reduce initial sporting  
183 performance or function. The injured group included mixed gender, sports and graft types,  
184 thus the ability to return to play with this deficit may not appear to affect any individual  
185 athletic group. However, more research is needed to confirm this hypothesis. Future work  
186 should consider larger samples of elite athletes with a longitudinal approach to proprioceptive  
187 assessment. If elite athletes are returning to international play with proprioceptive deficits  
188 then this may also provide a partial explanation for the high re-injury rates of this injury in  
189 athletic populations (Kamath *et al.*, 2014).

190 There is still substantial evidence that athletes with ACL-R will likely suffer from secondary  
191 injury problems (Bien and Dubuque, 2015). There is a significantly greater risk of suffering  
192 osteoarthritis in the damaged limb, occurring at ten times a greater rate in ACL-injured  
193 athletes, as well as higher risk of injury to the uninjured knee (Bahr and Krosshaug, 2005,  
194 Hewett *et al.*, 2007, Johansson *et al.*, 2000). Therefore again longitudinal study designs  
195 should monitor JPS of athletes that return to play to consider if proprioceptive deficits pre-  
196 dispose them to secondary injury problems.

197 In a recent expert consensus proprioceptive ability was not considered a component of return  
198 to play criteria used by clinical professionals (Lynch *et al.*, 2015) and therefore may not be  
199 thought important in the rehabilitation of an injured athlete. Furthermore, there does not  
200 appear to be substantial evidence of a strong relationship between joint position sense ability  
201 and functional performance (Gokeler *et al.*, 2012). However, recent evidence has suggested a  
202 link between threshold to detect passive motion, a measure of dynamic proprioceptive ability,  
203 and knee flexion and knee valgus at landing (Nagai *et al.*, 2013, Cronstrom and Ageberg,  
204 2014). These particular landing mechanics have been linked to ACL injury risk (Paterno *et*  
205 *al.*, 2010, Hewett *et al.*, 2005) and therefore future studies should consider the correlation  
206 between knee landing mechanics and knee joint position sense.

207 The joint position sense acuity of the uninjured knee in the elite athletic group did not differ  
208 significantly from the control group. This suggests for the athletes in the current study there is  
209 no heightened proprioceptive ability compared to controls as suggested in previous literature  
210 (Euzet and Gahery 1995, Han *et al.*, 2015, Waddington *et al.*, 2013). However, a limitation  
211 of research into ACL injury and proprioception is the majority of data collection is cross-  
212 sectional, which inevitably means pre-injury proprioception is unknown. Future studies may  
213 consider large scale JPS measurement screening of uninjured elite athletes using prospective  
214 designs to confirm or reject JPS as a risk factor to ACL injury.

215 A limitation of the current study is the potentially limited sample sizes (n=10), however  
216 differences were supported with accompanying large effect sizes. The study also assumed the  
217 athletes had all returned to the same level of function (international competition) as they had  
218 returned to elite level participation. This should be supported with more specific measures of  
219 function in future studies.

## 220 **Conclusion**

221 This study provides evidence of a reduced knee position sense in elite athletes who had  
222 returned to international level participation following ACL injury, reconstruction and  
223 rehabilitation. To the author's knowledge this is the first article to provide evidence of a JPS  
224 deficiency in international level sports performers on average of 6 months back into sports  
225 performance. The results may be clinically relevant as differences between injured and non-  
226 injured groups were greater than reported SDD values. However, as the injured athletes had  
227 returned to international level sport, it may also be JPS deficit does not reduce initial  
228 functional performance. Clinician should continue to monitor JPS ability once the athlete has  
229 returned to sport participation to see if this deficiency pre-disposes them to secondary injury  
230 or re-injury.

## 231 **Acknowledgements**

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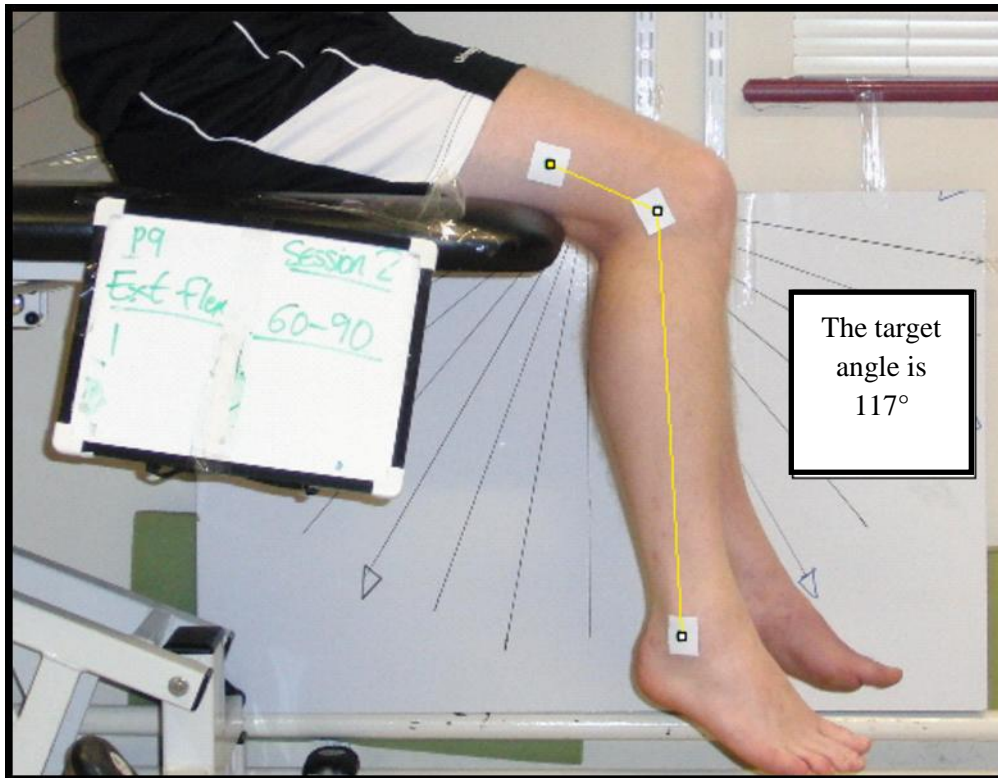
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**Table 1:** Knee joint position sense values into knee flexion

|                         | Mean Error Score $\pm$ SD (°) | 95% CIs |       | <i>P</i> value compared to ACLR Knee | Effect Size |
|-------------------------|-------------------------------|---------|-------|--------------------------------------|-------------|
|                         |                               | Lower   | Upper |                                      |             |
| ACLR knees              | 8.1 $\pm$ 1.24                | 7.3     | 8.9   |                                      |             |
| Contralateral knees     | 3.5 $\pm$ 0.72                | 3.1     | 4.0   | 0.0001                               | 0.98        |
| Uninjured control knees | 3.1 $\pm$ 1.84                | 2.0     | 4.2   | 0.0001                               | 0.92        |

**Table 2:** Knee joint position sense values into knee extension

|                         | Mean Error Score $\pm$ SD (°) | 95% CIs |       | <i>P</i> value compared to ACLR Knee | Effect Size |
|-------------------------|-------------------------------|---------|-------|--------------------------------------|-------------|
|                         |                               | Lower   | Upper |                                      |             |
| ACLR knees              | 7.2 $\pm$ 0.97                | 6.6     | 7.8   |                                      |             |
| Contralateral knees     | 1.9 $\pm$ 0.47                | 1.6     | 2.2   | 0.0001                               | 0.98        |
| Uninjured control knees | 2.8 $\pm$ 1.94                | 1.6     | 4.0   | 0.0001                               | 0.91        |



**Figure 1.** Typical set up and measurement of knee joint angle for knee joint position sense measurement



**Ethical Approval Panel for Post-graduate Programmes**

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22 July 2013

Dear Lee,

**RE: ETHICS APPLICATION 12/13-156** – Joint position sense in ACL deficient individuals

Following your responses to the Panel's queries, based on the information you provided, I am pleased to inform you that application 12/13-156 has now been approved. You may now proceed with your project.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible.

Yours sincerely,

*Frances Clarke*

Frances Clarke  
College Support Officer (T&L)