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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.

Article Type: Original Article

Section/Category: Basic Science

Keywords: Elite sport; proprioception; knee injury.

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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.

*Cover Letter

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Monday 15th 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. 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.

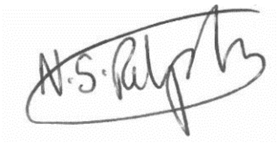
Yours Faithfully,

Dr Nicola Relph

***Conflict of Interest Statement**

Declaration of Interest

The authors report no declarations of interest.



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.

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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Introduction

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

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

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

Purpose and hypothesis

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

Materials and methods

Patient selection

Ten elite athletes (three male, seven female; age 22.4±3.75 years; three taekwondo competitors, three footballers, two netballers, one middle distance runner, one judo competitor) who had all undergone ACL reconstructive surgery (17.9±4.68 months since surgery; type of reconstruction; six hamstring, four bone-patellar tendon bone) took part in the study and were recruited using purposive sampling. All had returned to playing elite level sport (6.2±0.63 months since return to play; Lysholm score 94.2±1.69) at either a junior international (n=5) or senior international (n=5) level. All injured athletes had followed a criterion based rehabilitation programme as described in Herrington *et al*., (2012) and were not currently participating in any sensorimotor training. Ten healthy active participants (three male, seven female; age 22.1± 4.07years; Lysholm 100±0) acted as age, gender and sport matched controls. The controls were matched in this way as previous literature has suggested knee JPS may be influenced by such variables (Aydoğ *et al*., 2006; Nagai *et al*., 2012; Shaffer & Harrison, 2007). All participants were free from current lower extremity injury and any chronic disease that may affect proprioception such as visual or vestibular function, peripheral neuropathy and diabetes mellitus (Arockiaraj *et al*., 2013). Participants read an information sheet and provided written informed consent. This study was approved by the University ethics board (REP10/068).

Participants wore shorts and removed their socks and shoes. The participants were prepared for data collection by placing markers on the following anatomical points; a point on a line following the greater trochanter to the lateral epicondyle close to the lateral epicondyle (placement of a marker directly on the greater trochanter is difficult due to clothing), the lateral epicondyle and the lateral malleolus of both legs. The procedure was previously validated against an isokinetic dynamometer protocol (Relph & Herrington, 2015b). The intra-class correlation coefficients (ICC) value corresponding to inter-examiner reliability of the technique was 0.98 and Cronbach's Alpha was 0.99 in a previous study using identical procedures. Furthermore, the ICC value for intra-examiner reliability was 0.96 and Cronbach's Alpha was 0.98. Test-retest reliability has also been reported in a previous work as large for both knee flexion (ICC = 0.92) and knee extension (ICC = 0.86) procedures (Relph & Herrington, 2015a). The standard error of the measurement (SEM) was 0.40° and 0.60° for knee flexion and knee extension respectively (Relph & Herrington, 2015a). The smallest detectable difference (SDD) was 1.10° for knee flexion and 1.35° for knee extension measurements (Relph & Herrington, 2015a). This is an important addition to knee JPS research as previous studies have failed to adequately test the reliability of measurements before use (Beynnon *et al*., 2000; Relph *et al*., 2014; Ozenci *et al*., 2007; Gokeler *et al*., 2012).

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

Data Analysis

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

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

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

where *t* is the *t* statistic and *df* is the degrees of freedom.

Results

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

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

TABLE 1 AND 2 NEAR HERE

Discussion

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

There is no specific research on the knee JPS of elite athletic populations returning to international level performance following an ACL injury to support these findings. However, there is substantial evidence to support these findings in non-athletic populations (Relph *et al*., 2014, Angoules *et al*., 2011, Katayama *et al*., 2004, Baumeister *et al*., 2008). Results of a meta-analysis reported significantly greater knee JPS error scores in ACL reconstructed patients compared to both the contralateral leg and uninjured controls (Relph *et al*., 2014). Previous literature implies mechanoreceptors in the ACL provide afferent important information on the relative position and movement of the knee joint (Riemann and Lephart 2002, Johansson *et al*., 2000, Schultz *et al*., 1984). Therefore, ACL injury appears to impair proprioceptive ability through disruption of the transmission of this sensory information (Barrack and Munn, 2000). Marks *et al*., (2007) suggest this disrupted afferent information to the central nervous system consequently reduces joint position sense ability, this may explain the increased error scores in the current study. A history of elite level participation does not appear to negate the proprioceptive deficit following reconstructive surgery.

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

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

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

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

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

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

Conclusion

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

Acknowledgements

None

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Table(s)

Table 1: Knee joint position sense values into knee flexion

	Mean Error Score ± SD (°)	95% CIs			
		Lower	Upper		
ACLR knees	8.1±1.24	7.3	8.9	*P* value compared to ACLR Knee	Effect Size
Contralateral knees	3.5±0.72	3.1	4.0	0.0001	0.98
Uninjured control knees	3.1±1.84	2.0	4.2	0.0001	0.92

Table 2: Knee joint position sense values into knee extension

	Mean Error Score ± SD (°)	95% CIs			
		Lower	Upper		
ACLR knees	7.2±0.97	6.6	7.8	*P* value compared to ACLR Knee	Effect Size
Contralateral knees	1.9±0.47	1.6	2.2	0.0001	0.98
Uninjured control knees	2.8±1.94	1.6	4.0	0.0001	0.91

Figure(s)

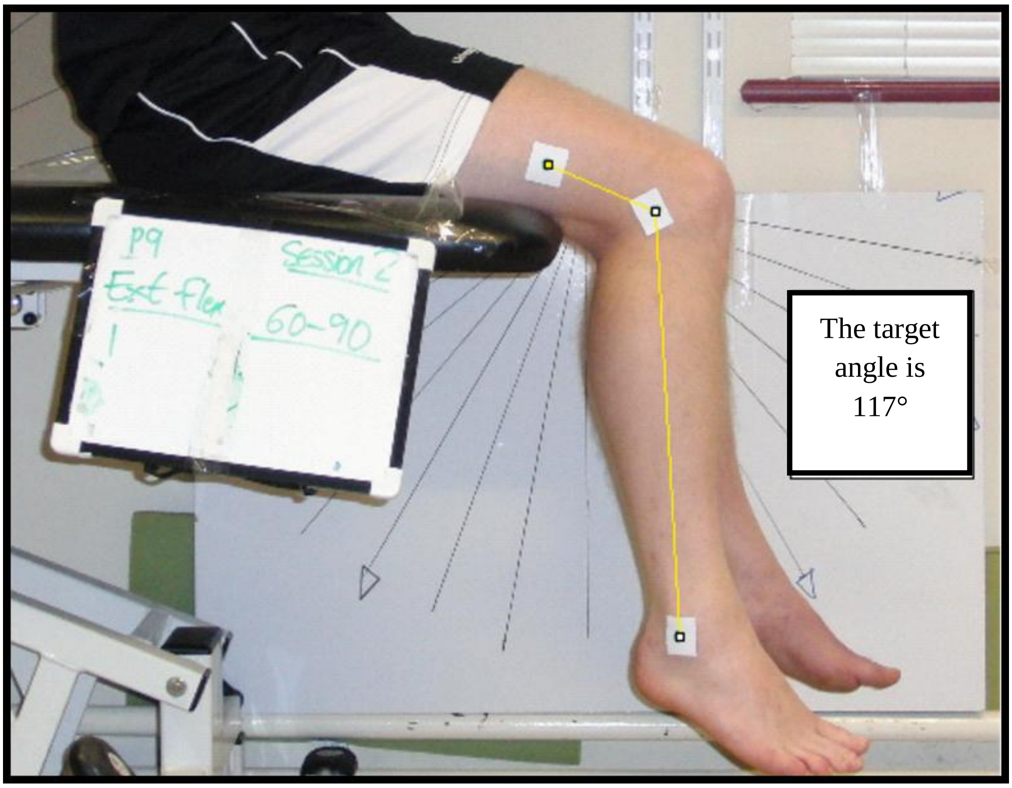

Figure 1. Typical set up and measurement of knee joint angle for knee joint position sense measurement

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)