

# THE MEASUREMENT OF KNEE JOINT POSITION SENSE

Nicola RELPH

School of Health Sciences  
College of Health & Social Care  
University of Salford, Salford, UK

Submitted in Partial Fulfilment of the  
Requirements of the Degree of Doctor of  
Philosophy, October 2015

# Contents

	<b>Page</b>
Title page	i
Table of contents	ii
Figures	viii
Tables	x
Acknowledgements	xii
Abstract	xiii
<b>Chapter 1</b>	
<b>Introduction</b>	
1.1 Anterior Cruciate Ligament (ACL) Injury and Knee Proprioception	2
1.2 Proprioception	2
1.3 Knee Proprioception	3
1.4 Knee Proprioception Measurement Techniques	4
1.5 Age and Knee Proprioception	5
1.6 Gender and Knee Proprioception	5
1.7 Body Mass Index and Knee Proprioception	6
1.8 Physical Activity and Knee Proprioception	6
1.9 Peripheral/ Muscular Fatigue and Knee Proprioception	7
1.10 Osteoarthritis and Knee Proprioception	8
1.11 Thesis Aims and Objectives	8

## Chapter 2

### Literature Review

2.1.1 The Effect of Anterior Cruciate Ligament Injury on Knee Proprioception	11
2.1.2 The Effect of Anterior Cruciate Ligament Injury on Static and Dynamic Knee Proprioception	12
2.1.3 Summary	24
2.2.1 The Sensorimotor System	29
2.2.2 Peripheral Afferent (Sensory) Pathways	30
2.2.3 Summary	35
2.2.4 Central Efferent Pathways	37
2.2.5 Efferent Information in Muscular Contraction	40
2.2.6 Summary	41
2.3.1 Knee Proprioception	41
2.3.2 The Anterior Cruciate Ligament (ACL)	42
2.3.3 The Posterior Cruciate Ligament (PCL)	43
2.3.4 Additional Knee Joint Mechanoreceptors	44
2.3.5 Summary	44
2.4.1 Measurement of Knee Proprioception	46
2.4.2 Joint Position Sense	50
2.4.3 Threshold to Detect Passive Motion	56
2.4.4 Summary	57
2.5.1 Normative Proprioception Levels	58
2.5.2 Age and Proprioception	58
2.5.3 Gender and Body Mass Index and Proprioception	63
2.5.4 Regular Physical Activity and Proprioception	65

2.5.5 Elite Athletic Populations and Proprioception	68
2.5.6 Fatigue and Proprioception	73
2.5.7 Osteoarthritis and Proprioception	80
2.6 Thesis Aims and Hypotheses	84

## Chapter 3

### Methodology

3.0 Introduction	88
3.1 The Test-Retest Reliability of Clinical Knee Joint Position Sense Measurement	90
3.2 Inter-Rater and Intra-Rater Reliability	104
3.3 Learning Effect Analysis to Determine the Required Number of Trials for Clinical Knee Joint Position Sense Measurement in three Conditions	105
3.4 The Consistency, Sensitivity and hence “Optimum Condition” for Clinical Knee Joint Position Sense Measurement – The Effects of Condition, Leg, Direction and Target Angle	106
3.5 Flow Chart to Illustrate the Decision Making Process to Ascertain the Optimum JPS Measurement Technique	110
3.6 The Construct Validity of Clinical Knee Joint Position Sense Measurement	114
3.7 Normative Knee Joint Position Sense Based on a UK Population.	117
3.8 Anterior Cruciate Ligament Deficient Knee Joint Position Sense in a Non-Athletic Population	121
3.9 Anterior Cruciate Ligament Deficient Knee Joint Position Sense in an Elite Athletic Population	124
3.10 Knee Injuries Other than Ligament Injury and Knee Joint Position Sense	127
3.11 Peripheral/ Muscular Fatigue and Knee Joint Position Sense	130

## Chapter 4

### Results

4.1 Normative Knee Joint Position Sense of an Adult UK Population	134
4.2 Anterior Cruciate Ligament Deficient Knee Joint Position Sense	139
4.2.1 Non-Athletic Population	139
4.2.2 Elite Athletic Population	139
4.3 Other Knee Injuries and Knee Joint Position Sense	141
4.4 The Effect of Peripheral/ Muscular Fatigue on Knee Joint Position Sense	142

## Chapter 5

### Discussion

5.0 Introduction	144
5.1 Optimum Environment for Knee Joint Position Sense Measurement	144
5.1.1 Test-ReTest Reliability of Knee Joint Position Sense Measurement.	144
5.1.2 Construct Validity of Knee Joint Position Sense Measurement	148
5.2 Normative Levels of Knee Joint Position Sense Measurement	149
5.2.1 The Effect of Knee Flexion and Extension on Knee Joint Position Sense Measurement	151
5.2.2 The Effect of Age on Knee Joint Position Sense Measurement	153
5.2.3 The Effect of Activity Levels on Knee Joint Position Sense Measurement	155
5.2.4 The Effect of Gender, Mass, Height and BMI on Knee Joint Position Sense Measurement	159
5.2.5 The Effect of Self-Reported Knee Condition on Knee Joint Position Sense Measurement	160
5.2.6 Summary	161

5.3 The Effect of Injury on Knee Joint Position Sense Measurement	162
5.3.1 A Non-Athletic Anterior Cruciate Ligament Population	162
5.3.2 An Elite Athletic Anterior Cruciate Ligament Population	163
5.3.3 The Effect of Additional Injuries on Knee Joint Position Sense Measurement	165
5.3.4 Summary	170
5.4 The Effect of Fatigue on Knee Joint Position Sense Measurement	170
5.5 Clinical and Functional Relevance	173
5.6 Limitations	178

## Chapter 6

### Conclusion

6.0 Conclusion	190
----------------	-----

### Appendices

#### Appendix 1: Published Studies

Appendix 1a: Relph, N., Herrington, L., and Tyson, S. (2014). The effects of ACL injury on knee proprioception: A meta-analysis. <i>Physiotherapy</i> , 100 (3), 187-195.	194
Appendix 1b: The scoring system used in the meta-analysis.	204
Appendix 1c: The characteristics of studies excluded from the meta-analysis	210
Appendix 1d: Relph, N., & Herrington, L. (2015). Inter-examiner, intra-examiner and test-retest reliability of clinical knee joint position sense measurements using an image capture technique. <i>Journal of Sport Rehabilitation</i> (in press).	227
Appendix 1e: Relph, N., & Herrington, L. (2015). Criterion-related validity of knee joint position sense measurement using image capture and isokinetic dynamometry. <i>Journal of Sport Rehabilitation</i> , Technical Report 10. ( <a href="http://dx.doi.org/10.1123/jsr.2013-0119">http://dx.doi.org/10.1123/jsr.2013-0119</a> ).	243

Appendix 1f: Relph, N., & Herrington, L. (2015). The Effect of Peripheral Fatigue on Knee Joint Position Sense. Paper presented at the <i>International Society of Biomechanics Conference</i> , Glasgow, UK.	255
Appendix 2: Participant Information Sheet for Clinical JPS Testing	257
Appendix 3: Participant Informed Consent Form for Clinical JPS Testing	259
Appendix 4: Isokinetic Dynamometer Protocol	261
Appendix 5: Participant Information Sheet for Peripheral Fatigue Study	263
Appendix 6: Participant Informed Consent Form for Peripheral Fatigue Study	265
References	267

# Figures

	Page
Figure 1: A PRISMA flow chart of article reduction.	20
Figure 2. The Sensorimotor System	29
Figure 3. A summary of findings from the literature review and the aims of the thesis.	85
Figure 4. Typical set up and measurement of knee joint angle for sitting JPS measurements.	91
Figure 5. Typical set up and measurement of knee joint angle for Prone Condition JPS measurement.	92
Figure 6. The Total Trainer Pilates Equipment, model TT2500P and an example of a participant on the equipment during collection of knee JPS.	94
Figure 7. Typical set up and measurement of knee joint angle for active condition JPS measurement.	94
Figure 8. Mean and Standard Error JPS Flexion and Extension Scores for a normative population.	135
Figure 9. A significant interaction between Gender and GPPAQ scores from JPS extension data.	135
Figure 10. Correlation between JPS extension absolute error scores and age.	136
Figure 11. Correlation between JPS extension absolute error scores and height.	136
Figure 12. Correlation between JPS extension absolute error scores and BMI.	137
Figure 13. Correlation between JPS extension absolute error scores and KOOS.	137
Figure 14. Correlation between JPS extension absolute error scores and Lysholm Score.	138

Figure 15. Correlation between JPS extension absolute error scores and Tegner Score.	138
Figure 16. Mean and Standard Error JPS Absolute Error Scores for a non-athletic ACL deficient and normative population.	139
Figure 17. Mean and Standard Error JPS into flexion Absolute Error Scores for an elite-athletic ACL deficient and normative population.	140
Figure 18. Mean and Standard Error JPS into extension Absolute Error Scores for an elite-athletic ACL deficient and normative population.	141
Figure 19. Mean and Standard Error JPS Absolute Error Scores pre and post fatiguing protocol.	142
Figure 20. Average absolute errors in the elbow ipsilateral matching of 30° targets for different cross sections of the human life span (taken from Goble et al., 2010).	150
Figure 21. Taken from Ashton-Miller et al., (2001) p.130. A more detailed scheme of the pathways and functions of proprioception.	184

# Tables

	Page
Table 1. Characteristics of the articles included in the meta-analysis (Relph et al., 2014).	14
Table 2. Methodological quality score for each of the articles included in the meta-analysis	17
Table 3. Receptor name, classification, axon type, location and adequate stimuli (adapted from Richards & Selfe (2012) and Lundy Ekman (2013)).	31
Table 4. Types of clinical proprioceptive testing (adapted from Suetterlin & Sayer, 2014, p.314).	48
Table 5. Age-related anatomical, physiological, central nervous system and clinical changes in proprioception (adapted from Shaffer and Harrison, 2007, p.197).	62
Table 6. Mean (°), standard deviation (SD), 95% confidence intervals (CI), standard error of measurement (SEM), smallest detectable difference (SDD) and intraclass correlation coefficient (ICC) values for the Real Error Score (RES).	98
Table 7. Mean, standard deviation (SD), 95% confidence intervals (CI), standard error of measurement (SEM), smallest detectable difference (SDD) and intraclass correlation coefficient (ICC) values for the Absolute Error Score (AES).	99
Table 8. Mean (°), standard deviation (SD), 95% confidence intervals (CI), standard error of measurement (SEM), smallest detectable difference (SDD) and intraclass correlation coefficient (ICC) values for the Real Error Score (RES).	100
Table 9. Mean (°), standard deviation (SD), 95% confidence intervals (CI), standard error of measurement (SEM), smallest detectable difference (SDD)	

and intraclass correlation coefficient (ICC) values for the Real Error Score (RES).	101
Table 10. Mean ( $^{\circ}$ ), standard deviation (SD), 95% confidence intervals (CI), standard error of measurement (SEM), smallest detectable difference (SDD) and intraclass correlation coefficient (ICC) values for the Real Error Score (RES).	102
Table 11. Mean, standard deviation (SD), 95% confidence intervals (CI), standard error of measurement (SEM), smallest detectable difference (SDD) and intraclass correlation coefficient (ICC) values for the Absolute Error Score (AES).	103
Table 12. Statistical analyses on the effects of absolute or error scores, leg, range of motion, direction and condition on knee JPS measurements.	108
Table 13. Participant details of study 3.7.	118
Table 14. Normative knee joint position sense values of an adult UK population.	134
Table 15. Mean and standard error JPS absolute error scores for knee injured patients and external matched controls.	141

# Acknowledgements

Foremost, I would like to express my sincere gratitude to my supervisor Dr. Lee Herrington for his motivation, enthusiasm and immense knowledge that provided continuous support to me. Your guidance helped me have the confidence to complete my research and thesis. Thank you. I also would like to give a massive thank you to Prof. Sarah Tyson whose guidance at the beginning of this journey was invaluable.

Thank you to those colleagues past and present who have provided constant advice and kindly read through numerous versions of thesis chapters. To all my participants, including some of those aforementioned colleagues, I thank you for your patience and time.

Finally, I would like to say a huge thank you to my family and friends who have supported me throughout the last six years. Mum and Dad, thank you for keeping me sane last year. Auntie Shirley and Uncle Alan, you made it possible for me to start this journey into postgraduate research and for that I cannot thank you enough. Cherrie, you have been my constant source of support, advice and knowledge and I am so grateful to you. Han, I could not have got through this without you, thank you for always making me smile and keeping things in perspective.

# Abstract

It is commonly stated proprioception or the perception of one's own limb position, movement and effort is reduced following an anterior cruciate ligament (ACL) injury. Therefore, this thesis begins with an analysis of all current literature on this topic in the form of a meta-analysis. It became clear that the methods used to measure knee proprioception were very inconsistent and did not appear to provide normative levels of knee proprioception making it very difficult to synthesise results. This led to the thesis main objectives. The first study provided a reliable and valid method of knee joint position sense (JPS), the static component of proprioception, based on previous JPS protocols. This method was then used in the remaining studies to consider normative values of a UK population, the effect of ACL injury in both non-athletic and elite athletic populations, the effect of knee injuries (not including ligament damage) and the effect of fatigue on knee JPS. The most appropriate clinical method of measuring knee JPS using image capture as covered in this thesis was in a sitting position, from full extension in to 60-90 degrees of flexion and from 90 degrees of flexion in to 30-60 degrees of extension. Age, mass, height, BMI, activity level, knee condition (other than ligament injury) or fatigue did not appear to significantly affect knee JPS in an uninjured population. However, both non-athletic and elite athletic populations with previous ACL injury demonstrated significantly worse knee JPS when compared to controls. In conclusion, it would appear the only knee condition that reduces joint position sense ability is ACL injury. Although, it may also be possible the method is not sensitive enough to measure subtle changes in JPS in other populations due to large measurement error values. In the future it may not be necessary to place importance on knee joint position sense as it either may not be impacted by any injury other than ACL damage, or the methods used to collect JPS are not sufficient in measuring changes during rehabilitation. Additionally, it is important researchers consider the relationship between knee JPS and functional movements.