AN INVESTIGATION OF PATIENT PROGRESSION THROUGH REHABILITATION WITH THE STEP-UP-AND-OVER TEST

by

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Abstract

The goal of surgery for patients undergoing anterior cruciate ligament reconstruction (ACLR) and subsequent rehabilitation is the restoration of normal knee function (van Grinsven et al., 2010). Having procedures that accurately assess and quantify recovery are crucial to ensure that physicians if patients are regaining knee function. However, there is no standardized, objective assessment of a patient’s improvement as they progress through the stages of rehabilitation. Currently, maximal effort testing is used to evaluate knee function to determine a patient’s readiness to return to unrestricted physical activity but, these tests place a high demand on the knee joint, which is contraindicated in early rehabilitation (Cascio et al., 2004) and may confound the patient’s results due to fear of re-injury. The step-up-and-over (SUAO) test is an objective, submaximal effort test that quantifies performance (van Grinsven et al., 2010) and, therefore, can be used to evaluate knee function throughout rehabilitation to gauge the patient’s progression.

Two studies were completed for this thesis. In the first study, 12 ACL-reconstructed individuals completed the SUAO test at each physiotherapy clinic visit until they were cleared to return to unrestricted physical activity by their physician or physiotherapist. They also completed the ACL-QoL, a questionnaire measuring the patient’s subjective knee function. In the second study, these 12 ACL-reconstructed patients completed a fear of re-injury questionnaire once a month and their pain was measured on each testing day to evaluate whether these two variables affected the results obtained from the SUAO test.

Results showed that the ACL-QoL was not related to the variables measured using the SUAO test and that the SUAO test was able to track an individual’s progression through rehabilitation. Results also showed that fear of re-injury did not affect the performance on each testing day but pain did. Together, these results indicate that the SUAO test is a clinically viable option to track an individual’s progression through rehabilitation without having fear of re-injury affect the results and that pain may affect performance of the SUAO test.
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Table of Contents

Abstract.................................................................................................................................................. ii
Acknowledgements .............................................................................................................................. iii
List of Figures ........................................................................................................................................ vi
List of Tables ......................................................................................................................................... ix
Chapter 1 General Introduction ........................................................................................................ 1
Chapter 2 Literature Review ............................................................................................................... 5
  2.1 ACL injury, treatment and rehabilitation ....................................................................................... 5
      2.1.1 Mechanisms of an ACL injury ................................................................................................. 5
      2.1.2 Biomechanical Risk Factors for ACL Injury .......................................................................... 5
      2.1.3 ACL injury treatment options .................................................................................................. 8
      2.1.4 Home-based versus Supervised Rehabilitation following ACL reconstruction .................. 9
      2.1.5 ACL reconstruction rehabilitation ......................................................................................... 10
      2.1.6 Patient outcome after ACL reconstruction rehabilitation ..................................................... 13
  2.2 Evaluating Knee Function during ACL reconstruction rehabilitation ........................................ 14
      2.2.1 Patient Questionnaires ........................................................................................................... 14
      2.2.2 Manual tests ............................................................................................................................. 17
      2.2.3 Maximal effort tests .................................................................................................................. 18
      2.2.4 Sub-maximal effort tests .......................................................................................................... 19
  2.3 Obstacles with clinical testing during ACL rehabilitation .......................................................... 21
Chapter 3 Evaluating the Progression of Knee Function During ACLR Rehabilitation with the Step-up-and-over test ............................................................................................................... 23
  3.1 Introduction ..................................................................................................................................... 23
  3.2 Procedure ....................................................................................................................................... 26
      3.2.1 Participants ............................................................................................................................... 26
      3.2.2 Questionnaires ......................................................................................................................... 26
      3.2.3 Protocol ..................................................................................................................................... 27
      3.2.4 Instrumentation ....................................................................................................................... 27
  3.3 Analysis .......................................................................................................................................... 28
  3.4 Results ............................................................................................................................................ 29
  3.5 Discussion ...................................................................................................................................... 34
  3.6 Conclusion ..................................................................................................................................... 37
Chapter 4 Effects of pain and fear of re-injury on Step-up-and-over performance in ACLR patients through rehabilitation

4.1 Introduction ........................................................................................................................................39
4.2 Methods ...........................................................................................................................................41
4.3 Results ...............................................................................................................................................43
4.4 Discussion .........................................................................................................................................46

Chapter 5 General Discussion .............................................................................................................50

References .............................................................................................................................................56

Appendix A : Letter of Information and Ethics Consent Forms ...............................................................81
Appendix B : Physical Activity Readiness Questionnaire Plus (PAR-Q+) ..................................................90
Appendix C : Mohtadi’s Anterior Cruciate Ligament Quality of Life (ACL-QoL) Questionnaire ...........94
Appendix D : SUAO and pain scores .......................................................................................................103
Appendix E : ACL-QoL and TSK-11 scores ...........................................................................................108
Appendix F : Graphs for SUAO and questionnaires scores and lines of progression .........................110
Appendix G : Shortened version of the TSK-11 ....................................................................................122
Appendix H : Pain Visual Analog Scale ................................................................................................123
Appendix I : Regression Models ........................................................................................................124
List of Figures

Figure 1-1. The starting position (left), lift (centre) and impact (right) phases of the SUAO test.............4

Figure 3-1. Example of the SUAO test. The body weight index from the IMU was calculated by subtracting 1 g. Also displayed are the Lift Acceleration (L), and Impact Acceleration (I)...........31

Figure 3-2. Lines of progression for the Lift Symmetry for all participants. Displayed are the computed lines of progression using a linear regression plotted from their first testing day and a computed last day of testing as measured from their surgery day. ..........................................................32

Figure 3-3. Lines of progression for the Impact Symmetries for all participants. Displayed are the computed lines of progression using a linear regression plotted from their first testing day score and a computed and last day of testing as measured from their surgery day. .........................................33

Figure 4-1. An example of a participant’s pain scores, fear or re-injury scores, lift symmetry, and impact symmetry scores according to days from surgery. The Pain Visual Analog Scale scores were reduced from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled to the other variables by dividing each score by 10 to give a range from 1.1-4.4; 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical .........45

Figure 4-2. Relationship between the lines of progression of the pain scores and the lift symmetry scores ........................................................................................................................................46

Figure F-1. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S01 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. .........110

Figure F-2. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S02 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. .........111

Figure F-3. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S03 according to days from surgery. The Pain Visual Analog Scale

vi
scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. ..........

Figure F-4. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S04 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. ..........

Figure F-5. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S05 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. ..........

Figure F-6. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S06 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. ..........

Figure F-7. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S07 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4; 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. ..........

Figure F-8. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S08 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. .........
Figure F-9. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S09 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. ........ 118

Figure F-10. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S10 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. ........ 119

Figure F-11. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S11 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. ........ 120

Figure F-12. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S13 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical. ........ 121
List of Tables

Table 3-1. Lines of progression for the lift and impact symmetry, ACL-QoL, the last testing day and the projected lift and impact symmetry days. ................................................................. 34
Table 3-2. Correlations (Pearson’s r) between the lines of progression of the Lift and Impact Symmetries (N=12) and the ACL-QoL ........................................................................................................ 34
Table D-1. Lift Acceleration, Impact Acceleration, and pain scores for each participant on each testing day ................................................................................................................................. 103
Table E-2. ACL-QoL and TSK-11 scores for each participant through rehabilitation ......................... 108
Table G-3. A shortened version of the Tampa Scale for Kinesiophobia (TSK-11) ............................... 122
Table H-4. Regression Models for all participants for the lift acceleration, impact acceleration, pain scores and fear of re-injury scores. ........................................................................................................ 124
Chapter 1

General Introduction

The anterior cruciate ligament (ACL) is the most commonly injured knee ligament. For every 1,000 exposures to sports activities the incidence of tearing one’s ACL is 0.22 in collegiate rugby, 0.33 in elite handball, 0.25 in collegiate wrestling, 0.17 in collegiate basketball, and 0.49 in alpine skiing (Prodromos, Han, Rogowski, Joyce & Shi, 2007). Unfortunately, this disruption of the ACL accounts for 91% of season ending injuries (Ford, Myer & Hewett, 2003; Wiggins, Grandhi, Schneider, Stanfield, Webster, & Myer, 2016). An ACL injury may also begin a course of events that includes instability, further injuries to ligaments and menisci, and the eventual deterioration of cartilage surfaces. Therefore, to mitigate the negative outcomes resulting from an ACL injury and to restore the original knee function as quickly and completely as possible, it is important for injured athletes, after surgical treatment, to engage in a program of supervised rehabilitation.

The goal of surgery and subsequent rehabilitation is the restoration of normal knee function, which is evaluated from injury through to surgery and across rehabilitation using functional, clinical, and subjective tests. Although the tests vary by clinic, the four most commonly used tests are the International Knee Documentation Committee Subjective Knee Form (IKDC-SKF), laxity tests, strength tests, and hop tests (Myer, Paterno, Ford, Quatman & Hewett, 2006; Shelbourne & Nitz, 1990; van Grinsven, van Cingel, Holla & van Loon, 2010; Werstine, 2009). The IKDC-SKF is a knee-specific questionnaire that evaluates a patient’s symptoms, function, and their ability to perform physical activities (Irrgang, Anderson, Boland, Harner, Kurosaks, Neyret, Richmond & Shelborne, 2001). A laxity test, often using the KT-1000 Knee Arthrometer, evaluates the knee’s anterior laxity (Harter, Osternig, Singer, James, Larson & Jones, 1988). The isokinetic strength tests evaluate the difference in strength between the affected and unaffected leg’s and compares the ratios of knee extensor torque to knee flexor torque in both legs (Myer et al., 2006; van Grinsven et al., 2010). The hop tests, which include the single leg hop, vertical hop, and the side hop,
evaluate maximal knee power as well as endurance (Gustavsson, Neeter, Thomeé, Silbernagel, Augustsson, Thomeé, & Karlsson, 2006; van Grinsven et al., 2010). Passing these tests, referred to as exit tests, either singularly or in combination indicates the return of normal function.

Rehabilitation following ACLR targets different post-surgical deficits at different stages. These stages are frequently divided into early and late stages, where the early stage of ACLR rehabilitation focuses on regaining full knee range of motion and progression towards full weight bearing to reduce any changes in gait, while the late stage begins to introduce high risk and high joint loading activities to target muscular strength, proprioception and neuromuscular control. Since the literature does not provide a standardized, objective assessment of an athlete’s progression through the stages of rehabilitation, the time when these activities are to be introduced is not clear (Shelbourne & Nitz, 1990; Myer et al, 2006; Wilk & Andrews, 1992). Although a general timeline is understood, each athlete must be treated based on their progress.

One factor that hampers the rehabilitation process is fear of re-injuring the ACL-reconstructed knee. This fear can influence an individual’s performance during rehabilitation which affects their recovery and if they are released from physiotherapy before they are fully recovered, they are at a higher risk for a subsequent ACL injury (Kvist, Ek, Sporrstedt & Good, 2005). The fear of re-injury can begin early in the rehabilitation process and may manifest during functional testing and persist beyond completion of rehabilitation and upon returning to unrestricted athletics (Ardern, Taylor, Feller, & Webster, 2011; 2012; Chmielewski, Jones, Day, Tillman, Lentz & George, 2008; Kvist et al., 2005). For example, maximal effort testing, such as the hop tests, which assess maximal knee power and endurance (Augustsson, Thomeé & Karlsson, 2004; Gustavsson et al., 2006; Paterno, Ford, Myer, Heyl, & Hewett, 2007; Thomeé, Neeter, Gustavsson, Thomeé, Augustsson, Eriksson, & Karlsson, 2012), stresses the patient’s knee and may promote the fear of re-injury. Movements that use forceful concentric and eccentric contractions, such as plyometric exercises, are also contraindicated early in rehabilitation due to the strength deficits in the graft that continue up to 12 weeks postoperatively (Cascio, Culp & Cosgarea, 2004; Lahav & Burks, 2005).
During testing, patients that experience fear of re-injury due to the forceful contractions required may underperform on a test to spare their knee thereby misrepresenting their knee function.

Due to their high demands, many functional tests are first completed at the 3-6-month stage of rehabilitation (Shaw, Chipchase, & Williams, 2004; van Grinsven et al., 2010) and, as a result, a patient’s progress cannot be tracked in the early stages. Measuring knee function early in rehabilitation could help estimate when a patient will be ready to return to unrestricted physical activity following rehabilitation and can serve as a cue that the rehabilitation process is not going as planned. Since maximal effort tests cannot be used early in the rehabilitation process, sub-maximal effort tests like the lunge test or the step-up-and-over (SUAO) test should be considered to track an individual’s progression through rehabilitation. These tests can be used earlier in the rehabilitation process to assess knee function and due to their sub-maximal nature, the results from these tests may not be influenced by a patient’s fear of re-injuring their knee. However, barriers to their implementation in the clinic such as the time to administer, time to score, their interpretability and cost must be considered.

Since a patient’s outcome is largely dependent on their progress through their rehabilitation program (Barber-Westin & Noyes, 2011), an inexpensive, objective assessment tool of low demand such as the SUAO test, which is fast and simple to administer, is required to assess knee function across the stages of rehabilitation. To perform the SUAO test, the patient begins by standing behind a 305mm high box, stepping on the box with the lead leg, carrying the trail leg over the box and landing on the surface opposite from the original starting position (Chmielewski, Wilk, & Snyder-Mackler, 2002; Lin, Hsu, Chang, Chiou, & Lu, 2010; Mattacola, Jacobs, Rund, & Johnson, 2004) (Figure 1.1). The variables extracted from the test that evaluate knee function include the Lift Acceleration, Impact Acceleration and Movement Time. The Lift Acceleration is the vertical acceleration recorded as the body is raised up onto the box, characterizing the concentric control of the lead leg’s knee extensors. The Impact Acceleration is the vertical acceleration recorded at the landing phase of the trail leg, characterizing the eccentric control of the lead leg’s knee extensors. Movement Time is the time from the commencement of the movement.
until the trail leg contacts the floor on the opposite side of the starting position and includes both the concentric and eccentric phases of the knee’s extensors. The SUAO test has required a force plate to measure the ground reaction force from which the key variables are extracted. However, an accelerometer can be used as an inexpensive alternative to the force plate (Bailey & Costigan, 2015). The SUAO test is an objective, submaximal effort test that quantitatively measures functional ability and, therefore, could be used throughout rehabilitation.

Figure 1-1. The starting position (left), lift (centre) and impact (right) phases of the SUAO test

The objectives of this thesis are 1) to use the SUAO test to investigate the progression pattern of knee function of patients undergoing ACLR rehabilitation (Chapter 4); 2) to determine if a relationship exists between the SUAO test performance through rehabilitation and subjective knee function with the use of the ACL-QoL (Chapter 4); and 3) to assess whether pain and fear of re-injury influences performance of patients during the SUAO test (Chapter 5).
Chapter 2

Literature Review

2.1 ACL injury, treatment and rehabilitation

2.1.1 Mechanisms of an ACL injury

ACL injuries can result from a direct contact to the knee from an object (inanimate, or another person), called contact mechanisms. The injuries that occur without physical contact are referred to as non-contact mechanisms. Approximately 70 percent of ACL injuries occur as a result of a non-contact mechanism (Agel, Arendt, & Bershadsky 2005; Alentorn-Geli, Myer, Silvers, Samitier, Romero, Lazaro-Haro, & Ramon, 2009; Arendt and Dick, 1995; Boden, Dean, Feagin, & Garrett, 2000; Kobayashi, Higuchi, Terauchi, Kobayashi, Kimura, & Takagishi, 2004; McLean, Huang, & van den Bogert, 2005; Tortora and Nielson, 2012). This mechanism can be characterized by a sudden deceleration, with the knee at 30 degrees of flexion or less, prior to a change of direction or during landing (Alentorn-Geli et al., 2009; Boden et al., 2000; McNair, Marshall, & Matheson, 1990; Olsen, Myklebust, Engebretsen, & Bahr, 2004; Sakane, Livesay, Fox, Rudy, Runco, & Woo, 1999; Shin, Chaudhari, & Andriacchi, 2009; Yu and Garrett, 2007). As a result of the deceleration and joint position, the tibia translates forward and rotates externally with the knee in valgus (Bahr and Krosshaug, 2005; Ford et al., 2003; Hewett, Myer, Ford, Heidt, Colosimo, McLean, & Succop, 2005; Krosshaug, Slauderbeck, Engebretsen, & Bahr, 2006; Levine, Kiapour, Quatman, Wordman, Hewett, & Demetropoulos, 2014; Markolf, Burchfield, Shapiro, Shepard, Finerman, & Slauderbeck, 1995; Olsen et al., 2004; Sakane et al., 1999; Shin et al., 2009; Woo, Debski, Withrow, & Janaushek, 1999, Woo, Abramowitch, Kilger, & Liang, 2006) causing excessive strain that compromises the ligament.

2.1.2 Biomechanical Risk Factors for ACL Injury

Risk factors for non-contact ACL injuries have typically been divided into intrinsic and extrinsic factors. Extrinsic factors include physical and visual perturbations, and shoe-surface interface (Alentorn-
Geli et al., 2009; Boden et al., 2000; Lim, Lee, Kim, An, Yoo, & Kwon, 2009). Intrinsic factors include anatomical differences such as a narrow intercondylar notch (Alentorn-Geli et al., 2009; Bahr and Krosshaug, 2005; Boden et al., 2000; Lim et al., 2009; Papalia, Franceschi, Tecame, D’Adamio, Maffulli, & Denaro, 2015; Tortora and Nielson, 2012), hormonal effects (Alentorn-Geli et al., 2009; Lim et al., 2009; Papalia et al., 2015) allowing for greater flexibility of ligaments, muscles and tendons (Boden et al., 2000; Tortora and Nielson, 2012), altered neuromuscular control (Boden et al., 2000; Lim et al., 2009; Papalia et al., 2015) and biomechanical differences (Alentorn-Geli et al., 2009; Lim et al., 2009; Papalia et al., 2015; Thomas, McLean, & Palmieri-Smith, 2010). Biomechanical risk factors are associated with an individual’s movement and include dynamic knee valgus, internal hip rotation, and vertical ground reaction force.

1. **Dynamic knee valgus.** Knee valgus load is viewed as an important predictor of ACL injury risk. Approximately 50% of all ACL injuries result from a dynamic valgus collapse of the knee (Kobayashi et al., 2004; Olsen et al., 2004) most often occurring during a landing or pivoting maneuver (Alentorn-Geli et al., 2009; Boden et al., 2000; McNair et al., 1990; Sakane et al., 1999; Shin et al., 2009; Yu and Garrett, 2007). Valgus alignment is correlated with a higher peak abduction moment and angle (Alentorn-Geli et al., 2009; Bencke, Curtis, Krogsheded, Jensen, Bandholm, & Zebis, 2013; Chaudhari, Hearn, Leveille, Johnson, & Andriacchi, 2003; Imwalle, Myer, Ford, & Hewett, 2009; McLean et al., 2005; Thomas et al., 2010) which may increase anterior tibial translation and loads on the ACL (Hewett et al., 2005). Additionally, in-vivo and cadaveric knee studies have shown that ACL strain increases with knee abduction (Chaudhari et al., 2003; Shin et al., 2009). Therefore, the absence of dynamic knee joint stability associated with valgus moments at the knee is a key biomechanical risk factor for ACL injury.

2. **Internal hip rotation.** Rotation at the hip may also contribute to dangerous kinematics that could lead to knee ligament injuries. Internal hip rotation has been observed during pivoting, landing and side-step cutting maneuvers, all of which are mechanisms of ACL injury (Bencke et al,
Asymmetry of abductor/adductor muscle activation at the hip may contribute to dynamic knee valgus and influence the torque experienced at the knee (Ford et al., 2003; Hewett et al., 2005; Imwalle et al., McLean et al., 2005; McLean and Samorezov, 2009; Pollard, Sigward, Ota, Langford, & Powers, 2006). As a result, internal rotation at the hip permits the patient’s entire lower extremity to move into positions frequently associated with ACL injuries, straining ligaments that stabilize the knee in the frontal plane. However, regardless of its relationship with knee abduction, internal hip rotation is an independent predictor of ACL injuries (Alentorn-Geli et al., 2009; Bencke et al., 2013; Paterno et al., 2010).

3. **Vertical ground reaction force.** In addition to dynamic knee valgus and internal hip rotation, the vertical ground reaction force may be a contributing risk factor for an ACL injury. Individuals with a decreased hip musculature and quadriceps femoris strength deficits tend to have a larger hip and knee flexion-extension angular velocity, thereby decreasing the muscular support available to absorb the landing force (Decker, Torry, Wyland, Sterett, & Steadman, 2003; Hewett et al., 2005; McCurdy, Walker, Saxe, & Woods, 2012; Thomas et al., 2010; Schmitt, Paterno, Ford, Myer, & Hewett, 2015; Yu and Garrett, 2007) increasing the risk of sustaining an ACL injury (Paterno et al., 2010). Additionally, erect landing postures increases the rate of force development thereby increasing the loads and stress placed on the ACL (Decker et al., 2003; McCurdy et al., 2012; Paterno et al., 2010; Thomas et al., 2010; Torry, Decker, Jockel, Viola, Sterett, & Steadman, 2004).

The biomechanics risk factors of excess dynamic knee valgus, internal hip rotation and vertical ground reaction force are associated with an increase in ACL injury risk. Unlike many risk factors, biomechanical risk factors can be mitigated with proper training (Chappell and Limpisvasti, 2008; Dempsey, Lloyd, Elliott, Steele, & Munro, 2009; Lim et al., 2009; McCurdy et al., 2012; Pollard et al., 2006; Zebis, Bencke, Anderson, Døssing, Alkjær, Magnusson, Kjær, & Aagaard, 2008) and therefore,
should be a focus during training for athletic activities and throughout ACL reconstruction (ACLR) rehabilitation.

### 2.1.3 ACL injury treatment options

Once a patient is diagnosed with an ACL tear, they are given the option to treat their ligament tear either conservatively or with surgery. The conservative treatment option does not require surgery and allows for a quicker return to sporting activities than does surgical treatment. With surgical treatment, a tissue graft is used to replicate the function of the ACL. An anatomic double-bundle ACL reconstruction technique successfully limits anterior tibial translation and may sufficiently control combined rotatory loads of internal and valgus and torque (Hussein, van Eck, Cretnik, Dinevski, & Fu, 2012; Karlsson, Irrgang, van Eck, Samuelsson, Mejia, & Fu, 2011; Kim, Asai, Woong, Sun, Hwang, Lee, & Fu, 2015; Samuelsson and Karlsson, 2009; Yagi, Wong, Kanamori, Debski, Fu, & Woo, 2002). As a result of the complex procedure, the surgical treatment of an ACL injury requires a lengthy rehabilitation process restricting patients’ physical activities levels for approximately six months after surgery (Shelbourne & Nitz, 1990). Therefore, both the patient and the clinician must decide the best course of treatment for this injury.

When making the decision regarding the best course of treatment, the clinician considers the patient’s age, their activities and degree of joint instability. Middle-aged individuals are less likely to receive surgical treatment (Brandsson, Kartus, Larsson, Eriksson, & Karlsson, 2000; Daniel, Stone, Dobson, Fithian, Rossman, & Kauffman, 1993). However, younger patients engage in more high-level activities and are more active than older patients, suggesting that type of activity and activity level are more important factors in deciding the course of treatment than is age (Brandsson et al., 2000; Magnussen, Lawrence, West, Toth, Talyor, & Garrett, 2012; Seng, Appleby, & Lubowitz, 2008). Patients who participate regularly in activities that involve decelerating, twisting, cutting, and jumping motions usually receive surgical treatment to stabilize the knee (Daniel et al., 1993). Without surgical treatment, knee joint hypermobility may contribute to future lower limb injuries including cartilaginous and meniscal damage (Fithian, Paxton, Stone, Luetzow, Csintalan, Phelan, & Daniel, 2005; Kessler, Behrend, Henz, Stutz,
Rukavina, & Kuster, 2008; Myer, Ford, Paterno, Nick, & Hewett, 2008). Additionally, patients with knee instabilities and those who wish to resume competitive sporting activities requiring rotational stability return to their pre-injury activity level more often if they receive surgery than if they receive conservative treatment (Brandsson et al., 2000; Fithian et al., 2005). A systematic review conducted by Ardern and colleagues (2014) reported that after ACLR, 81% of patients returned to any sport, 65% returned to their preinjury level of activity and 55% returned to competitive sports. For many clinicians and patients, the long-term reduction in knee joint laxity, future meniscal damage and surgery, and increases in knee function with surgery outweigh the short-term reduction in physical activity level.

2.1.4 Home-based versus Supervised Rehabilitation following ACL reconstruction

Following surgery, the patient can receive either supervised physical therapy at a rehabilitation clinic or follow a home-based rehabilitation program. Physical therapy is a service that is not always covered under an individual’s health insurance and the cost can range from $50-$150 per visit. If the cost of physical therapy is not covered under the patient’s health insurance, the patient may opt to rehabilitate their injury at home. For simple knee surgical procedures such as arthroscopic meniscectomy, no differences have been found between the rehabilitation methods (Beard and Dodd, 1998; Coppola and Collins, 2008; Grant & Mohtadi, 2010; Forster & Frost, 1982; Jokl, Stull, Lynch, & Vaughan, 1989; Wright, Preston, Fleming, Amendola, Andrish, Bergeld, & Williams, 2008) and some argue that a minimally supervised rehabilitation program is more effective in achieving acceptable range of motion than a supervised physical therapy program (Grant, Mohtadi, Maitland, & Zernicke, 2005). However, according to Ageberg and colleagues (2001), although muscular strength and functional performance can be restored with both an at home program and supervised physical therapy visits, the sensory system for maintenance of postural control may not fully recover with a home-based program. Therefore, supervised rehabilitation even if minimal may be an integral component of the overall management for patients that have a surgical reconstruction and for those that manage their injury conservatively but are ACL deficient (DeCarlo and Sell, 1997; Wright, Haas, Anderson, Calabrese, Cavanaugh, Hewett, & Wolf, 2015). Rehabilitation has
even been considered by some to be as important as the surgery itself (Beard and Dodd, 1998; Button, Roos, & van Deursen, 2014; Paulos, Noyes, Grood, & Butler, 1981).

2.1.5 ACL reconstruction rehabilitation

Following ACLR surgery, rehabilitation attempts to restore the patient’s normal knee function, which can be characterized by the ability to perform daily physical activities such as work, sports or activities of daily living effortlessly. Traditionally, ACL rehabilitation included prolonged immobilization, non-weight bearing exercises and slow progression towards activity. Today, the rehabilitation process is much different as clinicians focus on early weight bearing and more aggressively accelerate and facilitate earlier return to sport for athletes (Myer et al., 2006; Adams, Logerstedt, Hunter-Giordano, Axe, & Snyder-Mackler, 2012; van Grinsven et al., 2010; Wright et al., 2015).

Rehabilitation following ACLR is frequently divided into early and late stages where each stage targets different post-surgical deficits. The early stage of ACLR rehabilitation focuses on regaining full range of motion (ROM) and progression towards full weight bearing. In the late stage, high risk and high joint loading activities are introduced but there is no specified time when these activities are to be introduced (Shelbourne & Nitz, 1990; Myer et al., 2006; Wilk & Andrews, 1992). Progression through these stages of rehabilitation is dependent on the improvements in the patient’s graft strength and in knee function and it should be noted that there are no standardized measures for either of these. The strength of the graft is dependent upon fixation and is at its weakest during weeks 4 to 12 (Cascio et al., 2004; Lahav & Burks, 2005); therefore, rehabilitation protocols should provide the appropriate level of stress as to not injure the graft. Aspects of knee function that are addressed after surgery include: (Myer et al., 2006, Shelbourne & Nitz, 1990; van Grinsven et al., 2010; Werstine, 2009):

1. **Range of motion.** The knee’s range of motion (ROM) is limited following ACLR surgery. Attaining full knee extension in the early post-operative stage reduces pain, reduces atrophy of the quadriceps and arthrofibrosis, and prevents alterations in gait patterns and patellofemoral problems (Werstine, 2009; van Grinsven et al., 2010). Even losses of 3°-5° of knee extension
at full extension can adversely affect the subjective and objective results of rehabilitation (Adams et al., 2012). Therefore, stretching exercises to regain full active and passive ROM are begun immediately following surgery. It is essential to achieve a full and pain-free range of motion early to begin knee strengthening exercises and properly progress through the early stage of rehabilitation.

2. *Gait.* Differences in joint loading for both the affected and unaffected limbs can be seen immediately following ACLR (Button et al., 2014; Decker, Torry, Noonan, Riviere, & Sterett, 2002; DeVita, Hortobagy, & Barrier, 1998; Ernst, Saliba, Diduch, Hurwitz, & Ball, 2000; Kaur, Ribeiro, Theis, Webster, & Sole, 2016; Kvist, 2004; Mattacola, Perrin, Gansneder, Gieck, Saliba, & McCue, 2002; Noehren, Wilson, Miller, & Lattermann, 2013; Paterno et al., 2010; Pinczewski, Lyman, Salmon, Russell, Roe, & Linklater, 2007; Salem, Salinas, & Harding, 2003; Tashman, Collon, Anderson, Kolowich, & Anderst, 2004; von Porat, Henriksson, Holmström, Thorstensson, Mattsson, & Roos, 2006). The altered kinetics during gait, although they allow for an adequate performance, increase the risk of a subsequent ACL injury (DeVita et al., 1998; Kaur et al., 2016; Noehren et al., 2013; Paterno et al., 2010; Salmon, Russell, Musgrove, Pinczewski, & Refshauge, 2005; Di Stasi, Logerstedt, Gardinier, & Snyder-Mackler, 2013; Wright, Dunn, Amendola, Andrish, Bergfeld, Kaeding, & Spindler 2007). Therefore, clinicians emphasize early weight bearing to reduce patellofemoral pain and the risk of any long-term changes in the landing strategy used during gait (Decker et al., 2002; Shelbourne & Nitz, 1990; Wright et al., 2015).

rehabilitation to mitigate changes in muscle timing and recruitment order. The re-establishment of neuromuscular control is one of the keys to restoring dynamic joint stability and functional movement patterns that reduce the risk of future injuries (Risberg, Holm, Myklebust, & Engebretsen, 2007; Werstine, 2009; Wright et al., 2015).

4. **Cardiovascular fitness.** Unfortunately, patients are unable to maintain their pre-injury cardiovascular fitness level after their ACL injury. Atrophy of both type I and type II quadriceps muscle fibers have been found in ACL-deficient individuals (Werstine, 2009) indicating that both muscular strength and endurance should be trained to regain pre-injury fitness levels. As a result, the intensity of cardiovascular exercises increases as patients progress through the stages of rehabilitation (Shelbourne & Nitz, 1990; Werstine, 2009) with the goal of returning to their pre-injury level of physical activity.

5. **Muscular strength.** Since high knee loading is a factor in predicting ACL injuries (Hewett et al., 2005), it is important to increase the knee’s flexor and extensor strength so that they provide support to the knee when experiencing high loads. Although current rehabilitation protocols emphasize knee flexor and extensor strength training, deficits in muscular strength in the affected limb, independent of autograft donor site, have been seen following return to unrestricted sports activities (Hiemstra, Webber, MacDonald, & Kriellars, 2000, 2007; Keays, Bullock-Saxton, & Keays, 2000; Mattacola et al, 2002; Natri et al., 1996; Palmieri-Smith and Lepley, 2015; Schmitt et al., 2015; von Porat et al., 2006, Wilk, Romaniello, Soscia, Arrigo, & Andrews, 1994). Therefore, it is important to target the strength deficits of the graft-harvested muscles, particularly knee extensor strength, before properly progressing to more demanding movements during rehabilitation.

The post-surgical deficits seen in a patient with an ACL injury include a decrease in joint range of motion, modified gait, reduced proprioception and neuromuscular control, reduced cardiovascular fitness and reduced muscular strength, all of which must be targeted throughout the stages of rehabilitation.
2.1.6 Patient outcome after ACL reconstruction rehabilitation

Despite a strong understanding of the post-operative knee deficits that need to be addressed, patient outcomes following the surgical procedure, which is successful for many ACL-deficient individuals, are not always favorable. While reconstructive surgery and subsequent rehabilitation corrects knee joint laxity, protects against abnormal meniscal loads and improves subjective knee function (Barber-Westin, & Noyes, 2011; Fithian, Paxton, Stone, Lou, Luetzow, Csintalan, Phelan, & Daniel, 2005; Kessler et al., 2008; Papageorgiou, Gil, Kanamori, Fenwick, Woo, & Fu, 2001), many patients are still unable to return to their pre-injury level of physical activity (Fithian et al., 2005; Kvist et al., 2005). In addition, those that do return to physical activity participation have an increased risk of sustaining a subsequent ACL injury, either a repeat injury or an injury to the contralateral ACL (Kyritsis, Bahr, Landreau, Miladi, & Witvrouw, 2016; Paterno et al., 2010; Paterno, Rauh, Schmitt, Ford, & Hewett, 2014; Pinczewski et al., 2007; Salmon et al., 2005; Schmitt et al., 2015; Wright et al., 2007). Up to 30% of young patients who undergo ACLR suffer a subsequent ACL rupture in the first few years after surgery (Paterno et al., 2014; Webster, Feller, Leigh, & Richmond, 2014). Unfortunately, despite surgical or nonsurgical intervention, ACL injuries are also responsible for the increased risk of developing early-onset osteoarthritis (Lohmander, Englund, Dahl, & Roos, 2007; Luc, Gribble, & Pietrosimone, 2014; McLean et al., 2005; Paterno et al., 2010; Paterno et al., 2014; Schmitt et al., 2015; Schroeder, Krishnan, & Dhaher, 2015; von Porat, Roos, & Roos, 2004). It is well-known that osteoarthritis is usually associated with varying degrees of pain, stiffness, and functional impairment. Therefore, to mitigate the number of patients that have a poor post-ACLR outcome and develop early-onset osteoarthritis, an objective measure of functional ability is required for individuals undergoing ACLR rehabilitation.

The variability in a patient’s outcome following ACLR could be attributed to the current evaluation criteria used to determine when to release a patient from rehabilitation and clear them to perform at their pre-injury level of physical activity. The current goal is to return patients to unrestricted sports activities within six months (Keays et al., 2000; Shelbourne & Nitz, 1990; Di Stasi et al., 2013). This criterion does not seem appropriate since many patients fail their functional tests after six months, increasing their risk of...
sustaining an ACL graft rupture (Kyritis et al., 2016, Di Stasi et al., 2013). For instance, to pass the single-leg horizontal hop test, a common functional test used in rehabilitation to evaluate knee function, the affected limb must have a performance of at least 85% compared to the unaffected limb. Unfortunately, by this criterion fewer than half of patients pass after six months of rehabilitation (Thomeé et al., 2012). A systematic review published by Harris and colleagues (2014) found that 57% of the 49 ACLR articles selected use the amount of time postoperatively as their only criterion for return to sport. Additionally, 65% failed to provide any criteria for return to sport after ACLR and only 10% provided some measurable, objective criteria that patients had to achieve before resuming unrestricted athletics. As a result, an alternative evaluation of knee function during rehabilitation is required to increase an athlete’s successful reintegration into sport at the same competitive level as prior to their injury.

2.2 Evaluating Knee Function during ACL reconstruction rehabilitation

Unfortunately, there is no consensus regarding the content of an ACLR rehabilitation program. However, there are many subjective and objective measures that can be used during the course of rehabilitation to evaluate knee function to determine the speed and safety with which an athlete can return to sport or regains their pre-injury level of function. Subjective measures are evaluated using patient questionnaires while objective measures are evaluated with manual tests, maximal effort tests, or sub-maximal effort tests. With the abundance of measures, it can be difficult for clinicians to decide the appropriate test(s) to use in each stage of rehabilitation. Clinicians must evaluate and compare each test’s advantages and disadvantages to make an evidence-based decision regarding the best course of treatment for their patient.

2.2.1 Patient Questionnaires

A variety of patient questionnaires have been developed to subjectively evaluate knee function (Briggs, Lysholm, Tegner, Rodkey, Kocher, & Steadman 2009; Irrgang et al., 2001; Lundberg, Styf, & Carlsson, 2004; Marx, Stump, Jones, Wickiewicz, & Warren, 2001; Marx, Jones, Allen, Altchek, O’Brien, Rodeo, & Wickiewicz, 2001; Mohtadi, 1998; Sullivan, Bishop, & Pivik, 1995; Woby, Roach, Urmston, &
Watson, 2005). As a result, it can be difficult to decide which one(s) to administer. To elucidate the scope of knee function questionnaires, they have been classified according to the aspect being evaluated.

1. **Global knee function.** The questionnaires that may be administered to assess many aspects of knee function include: The International Knee Documentation Committee Subjective Knee Form (IKDC-SKF) (Irrgang et al., 2001), the Knee Injury and Osteoarthritis Outcome Score (KOOS) (Roos, Roos, Lohmander, Ekdahl, & Beynnon, 1998), the Cincinnati Knee-Rating System and the Lysholm Scale (Marx, Jones, et al., 2001). Of these four questionnaires, the IKDC-SKF is the most effective because, unlike other questionnaires, the data obtained from this questionnaire can be compared to normative scores (Anderson, Irrgang, Kocher, Mann, & Harrast, 2006). These normative scores, developed for healthy men and women, can be used to indicate if a patient is ready to return to unrestricted physical activity (Myer et al., 2006). The IKDC-SKF is considered both a valid and reliable questionnaire (Irrgang et al, 2001) measuring symptoms, function and sports activities (Anderson et al., 2006; Myer et al., 2006). However, the IKDC-SKF evaluates fewer domains of knee function than other global knee function questionnaires. For instance, the Cincinnati-Knee Rating System and the Lysholm Scale are both reliable, valid and responsive questionnaires measuring symptoms, pain and activity level (Marx, Jones et al., 2001). The KOOS measures daily living activities, pain and quality of life and was identified along with the IKDC-SKF as the top global knee function instruments (Collins, Misra, Felson, Crossley, & Roos, 2011; Tanner, Dainty, Marx, & Kirkley, 2007). Each domain of knee function in the KOOS is measured independently, which may provide a more detailed assessment of knee function than the IKDC-SKF (Roos et al., 1998). If a more detailed understanding of knee function is desired, additional domains of knee function can be measured using additional questionnaires (Briggs et al., 2009; Lundberg et al., 2004; Marx, Stump et al., 2001; Sullivan et al., 1995; Woby et al., 2005). The IKDC-SKF is important to patients as it ensures their perspective is considered (Tanner et al., 2007) and it provides a
single overall normative score, which is not possible with other global knee function questionnaires.

2. **ACL-specific knee function.** A reliable injury-specific, subjective outcome measure for ACL-deficient individuals is Mohtadi’s ACL Quality of Life (ACL-QOL) questionnaire (Mohtadi, 1998). This questionnaire measures symptoms, sports activities, daily living activities, work activities and quality of life and is considered more important to ACL-deficient patients than global knee function questionnaires (Tanner et al., 2007). Unfortunately, this disease-specific quality of life measure has not been validated for ACL-deficient patients and does not have normative standards (Mohtadi, 1998).

3. **Domain of knee function.** To get a clear understanding of a patient’s ability to recover following ACLR, clinicians must evaluate different constructs of knee function. These constructs include a patient’s fear of pain, fear of re-injury and activity level, all of which can be evaluated through questionnaires. These specific constructs can be considered as knee function domains since they may be related to global knee function (Chmielewski et al., 2008; Kvist et al., 2005). The fear of pain, assessed using the Pain Catastrophizing Scale (PCS), can predict an individual’s physical activity tolerance (Sullivan, et al., 1995, Sullivan, Stanish, Waite, Sullivan, & Tripp, 1998; Sullivan, Rodgers, Wilson, Bell, Murray, & Fraser, 2002). A patient’s fear of pain relating to physical activity, which is a major component of rehabilitation, can greatly influence their rate of recovery. The recovery process can also be influenced by a patient’s fear of re-injury which can be quantified using either the Tampa Scale for Kinesiophobia (TSK) or the shortened version (TSK-11) (Lundberg et al., 2004; Woby et al., 2005). As with fear of pain, pain-related fear of movement/re-injury may influence functional outcome in patients with ACLR. Patients who are more fearful of re-injury are less likely to return to the same level of unrestricted sports activities post-operatively (Chmielewski et al., 2008; Kvist et al., 2005, Tripp, Stanish, Ebel-Lam, Brewer, & Birchard, 2007). It is also important for clinicians to
evaluate a patient’s activity level because physical activity is a large component of ACLR rehabilitation and a fear of pain during activity may affect their recovery. The patient’s activity level can be assessed with either the Tegner Activity-Level Scale (Briggs et al., 2009) or Marx Activity-Rating Scale (Marx, Stump, et al., 2001) to see if they have returned to their pre-injury activity level, an important factor in determining the success of ACLR (Kvist et al., 2005). Further insight into a patient’s recovery is gained by measuring fear of pain, fear of re-injury and activity level.

Although questionnaires are important to patients and are valuable measures of knee function, they are subjective. The patient’s opinion cannot provide a complete assessment of knee function; therefore, questionnaires should be used in conjunction with objective and functional outcome measures included in the clinician’s assessment.

2.2.2 Manual tests

Manual tests are objective assessment measures clinicians use to evaluate knee joint laxity. Since an ACL injury increases the anterior laxity of the knee joint (Daniel, Lou, Sachs, & Malcom 1985), the ability of the ACL graft to withstand anterior motion is an important assessment of knee stability. Knee joint laxity is assessed using the Lachman’s, anterior drawer and pivot shift tests (Katz & Fingeroth, 1986); however, the KT 1000 arthrometer returns more objective measures (Daniel et al., 1985).

The KT-1000 arthrometer quantifies anterior tibial translation at the knee joint. Displacement loads are recorded with the use of an audio tone which signals when the desired force is applied through the force-sensing handle and the joint displacement due to laxity and can be read with an accuracy of 0.5 millimeters (Daniel et al., 1985). This test effectively diagnoses ACL tears (Daniel et al., 1985). However, its ability to evaluate knee function after ACLR remains in question due to the complexity of the relationship between a patient’s subjective knee function and their joint laxity since knee function and knee laxity are not always related (Harter et al., 1988; Kocher, Steadman, Briggs, Sterett, & Hawkins, 2004; Myer, Ford, Paterno, & Hewett, 2008; Risberg, Holm, Tjomsland, Ljunggren, & Ekeland, 1999; Ross, Irrgang, Denegar, McCloy,
& Unangst, 2002). According to Myer and colleagues (2008) knee joint laxity may be a predictor of an ACL re-injury although others disagree (Paterno et al., 2010; Uhorchak, Scoville, Williams, Arciero, St. Pierre, & Taylor, 2003). Therefore, the arthrometer test may be able to identify patients at a higher risk of sustaining a subsequent ACL-injury; however, the test cannot be used to evaluate knee function throughout the rehabilitation process.

2.2.3 Maximal effort tests

In the final stages of rehabilitation clinicians use maximal effort tests to assess knee function (Myer et al., 2006; Di Stasi et al., 2013; van Grinsven et al., 2010; Werstine, 2009). These tests include the isokinetic knee strength (Keays et al., 2000; Lephart, Ferris, Riemann, Myers, & Fu, 2002; Mattacola et al., 2002; Wilk et al., 1994), single-leg vertical hop (Gustavsson et al., 2006), single-leg horizontal hop (Gustavsson et al., 2006), drop vertical jump (Ford et al., 2003), and agility tests (Myer et al., 2006; Pauole, Madole, Garhammer, Lacourse, Rozenek, Education, & Beach, 2000). The most commonly used tests are the isokinetic knee strength and the single-leg horizontal hop tests both of which are valid and reliable indicators of change in knee function (Myer et al., 2006; Shaw et al., 2004; van Grinsven et al., 2010; Werstine, 2009).

An isokinetic dynamometer measures maximal quadriceps and hamstring muscle strength (Keays et al., 2000; Lephart et al., 2002; Wilk et al., 1994). The patient’s leg is secured to the device such that the knee is the only moving joint. The patient then completes a series of knee extension/flexion cycles at maximal effort. Knee function is evaluated by comparing the peak torques of the unaffected to the peak torques of the affected leg, where the symmetry is the ratio of peak knee extensor torque to the peak knee flexor torque (Myer et al., 2006; van Grinsven et al., 2010). Isokinetic testing is often chosen due to its inherent patient safety, objectivity and reproducibility (Wilk et al., 1994). However, the test does not standardize the angular velocity, range of motion, and number of cycles making it challenging to compare research results (Keays et al., 2000; Lephart et al., 2002; Mattacola et al., 2002; Wilk et al., 1994).
The single-leg horizontal hop test is considered a more consistent maximal effort test in measuring knee function (Gustavsson et al., 2006). This test requires the patient to perform a single-leg hop by standing on one leg, hopping as far as possible in the forward direction and landing on the same leg or on both legs. Side-to-side differences are commonly used to determine readiness for discharge from rehabilitation and readiness to return to physical activity safely after ACLR (Myer et al., 2006; Paterno et al., 2007; van Grinsven et al., 2010; Werstine, 2009; Wilk et al., 1994).

Although these maximal effort tests are objective measures of knee function, fear of re-injury and the limited ability to perform these tasks throughout rehabilitation due to the high demands required of the knee, such as maximal power and strength, may confound the patient’s performance thereby limiting the test’s accuracy. An individual’s fear of re-injuring their knees may sometimes slow the rehabilitation process and this fear may persist beyond release from rehabilitation to unrestricted physical activity (Ardem et al., 2012; Chmielewski et al., 2008; Kvist et al., 2005). These maximal effort tests also place high demands on the ACL-reconstructed knee that is contraindicated early in rehabilitation (Cascio et al., 2004; Lahav & Burks, 2005). As a result, there is no current evaluation of dynamic knee function being conducted in the early phases of rehabilitation. Evaluating knee function throughout rehabilitation is important to be able to determine a patient’s readiness to perform more demanding movements. However, a less demanding, objective test that quantitatively measures functional ability would be required in the early phases of rehabilitation.

2.2.4 Sub-maximal effort tests

If maximal effort tests cannot be performed due to their high demands, knee function can be evaluated with sub-maximal effort tests. These tests, although not as common in the literature as maximal effort tests, include the joint position sense, forward lunge and step-up-and-over tests (Alkjaer, Henriksen, Dyhre-Poulsen, & Simonsen, 2009; Alkjaer, Simonsen, Magnusson, Aagaard, & Dyhre, 2002; Chmielewski et al., 2002; Harter et al., 1988; Lin et al., 2010; Mattacola et al., 2004).
1. **Joint position sense test.** The joint position sense test is commonly performed by passively moving the knee joint to different target angles and having the patient reproduce these positions of knee flexion (Gokeler, Benjaminse, Hewett, Leiphart, Engebretsen, Ageberg, & Dijkstra, 2012; Harter et al., 1988). By removing the patient’s sight while the knee is positioned passively the test can assess knee joint proprioception. While it is important to retrain proprioception in ACLR rehabilitation, evidence suggests that performance on the joint position sense test is not clinically relevant and does not accurately reflect overall knee function (Gokeler et al., 2012; Harter et al., 1988).

2. **Forward lunge test.** The forward lunge test is performed by taking one step forward onto a force plate with the lead leg, flexing the knee to 90°, followed by extending the knee to return to the original standing position (Alkjaer et al., 2002; Alkjaer et al., 2009; Mattacola et al., 2004). Measures of impact index, movement time and knee extensor moment can help assess the differences between affected and unaffected legs of patients with ACL injuries, individuals with ACLR, and between ACL-deficient patients and ACL-intact individuals (Alkjaer et al., 2002; Mattacola et al., 2004).

3. **SUAO test.** The SUAO test is performed on a force plate by stepping up on a 305mm high box with the lead leg, swinging the trail leg over the box and landing with the trail leg contacting the force plate on the opposite side of the box (Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004). Measures of lift-up index, impact index and movement time can assess the differences between affected and unaffected legs of patients with ACLR, and between ACL-deficient patients and ACL-intact populations (Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004).

Knee function can be evaluated using patient questionnaires, manual tests conducted by clinicians, and maximal and sub-maximal effort tests performed by patients. To make an evidence-based decision regarding a patient’s course of treatment, clinicians must use a combination of tests as there is no
standardized objective measure of assessing knee function throughout the rehabilitation process (Barber-Westin, & Noyes, 2011; Myer et al., 2006; Di Stasi et al., 2013). The use of a standardized, objective test would enable clinicians to measure an individual’s progress and allow clinicians to make any necessary changes to the patient’s course of treatment accordingly. The forward lunge and SUAO tests may be two methods of assessing sub-maximal knee function and evaluate progression throughout rehabilitation. Both tests have clear measures that score ACL-intact individuals, ACL-deficient individuals and ACL-reconstructed patients differently. Currently, these tests are conducted using expensive laboratory equipment that may not be readily available in the clinic.

2.3 Obstacles with clinical testing during ACL rehabilitation

There are obstacles that prevent patients in a clinic from performing a dynamic, lab-based test of knee function throughout the rehabilitation process. As previously discussed, some tests are highly demanding which may cause fear of re-injury and, in addition, are contraindicated in the early stages of rehabilitation. Sub-maximal tests such as the lunge test and the SUAO test may be used throughout ACLR rehabilitation to assess knee function. However, these tests currently use expensive devices such as a force plate that may not be affordable for many clinics and may require technical expertise that is not readily available. Other barriers to a test’s implementation include the time to administer, time to score, and interpretability. Therefore, to be implemented, tests must consider the needs of the clinic and unfortunately, there is no current test that is objective, of low demand and inexpensive.

To decrease the expense of sub-maximal tests of knee function, Bailey & Costigan (2015) investigated the use of an accelerometer for the SUAO test. A 3-axis, wireless accelerometer and signal transmitter/receiver, such as YEI Technologies’ Wireless Sensor and Dongle (2015), can be used to accurately estimate segment and joint kinematics (Mizuike, Ohgi, & Morita, 2009; Moe-Nilssen, 1998). A single accelerometer can also assess the knee’s kinetics using the lift acceleration and impact acceleration measures obtained from the SUAO test. The measures obtained from an accelerometer are highly correlated
to those from a force plate (Bailey & Costigan, 2015) making a wireless, 3-axis accelerometer a less expensive and more portable system with which to measure the SUAO test.
Chapter 3

Evaluating the Progression of Knee Function During ACLR Rehabilitation

with the Step-up-and-over test

3.1 Introduction

After an anterior cruciate ligament reconstruction (ACLR), it can take 6 months to a year of rehabilitation before a patient regains their normal lower limb kinetics, kinematics and limb strength and those who return to their pre-injury sporting activities have an increased risk of sustaining a subsequent ACL injury (Kyritsis et al., 2016; Paterno et al., 2010; Paterno et al., 2014; Pinczewski et al., 2007; Salmon et al., 2005; Schmitt et al., 2015; Wright et al., 2007). Although the exact cause for the increased risk of injury is not known, the surgical treatment and rehabilitation of an ACL injury may not adequately restore a patient’s knee function and deficits may be present for up to five years after surgery, preventing the safe return to unrestricted sport activities (Decker et al., 2002; Hiemstra et al., 2000, 2007; Paterno et al., 2010). It is therefore important to mitigate the deficits seen following ACLR to decrease the risk of sustaining a subsequent injury to either the ACL-reconstructed knee or the contralateral limb.

Rehabilitation following ACLR is frequently divided into early and late stages where each stage targets different post-surgical deficits. The early stage of ACL rehabilitation focuses on regaining full range of motion (ROM) and progression towards full weight bearing. In the late stage, high risk and high joint loading activities are introduced but there is no specified time when these activities are to be introduced (Shelbourne & Nitz, 1990; Myer et al, 2006; Wilk & Andrews, 1992). Progression through these stages of rehabilitation is dependent on the improvements in the patient’s graft strength and in knee function and it should be noted that there are no standardized measures for either of these. The strength of the graft is dependent upon fixation and is at its weakest during weeks 4 to 12 (Cascio et al., 2004; Lahav & Burks, 2005); therefore, rehabilitation protocols should provide the appropriate level of stress as to not injure the graft.
While reconstructive surgery and subsequent rehabilitation corrects knee joint laxity, protects against abnormal meniscal loads and improves subjective knee function (Barber-Westin, & Noyes, 2011; Fithian et al., 2005), many patients are still unable to return to their pre-injury level of physical activity (Fithian et al., 2005; Kvist et al., 2005). In part, this could be because there is no consensus regarding the content of an ACLR rehabilitation program. However, a patient’s knee function is evaluated directly after injury through to surgery and during their rehabilitation using subjective, functional, and clinical tests. These tests evaluate knee function to determine the speed and safety with which an athlete can return to sport or regain their pre-injury level of physical activities. Subjective measures are evaluated using patient questionnaires such as the Anterior Cruciate Ligament Quality of Life (ACL-QoL) a questionnaire that is valid and reliable, evaluates symptoms, sports activities, daily living activities, work activities and quality of life and may be used to evaluate knee function subjectively or one’s readiness to return to sporting activities (Tanner et al., 2007). A positive self-reported function from the patient is an important aspect of an ACLR rehabilitation evaluation. However, this evaluation is subjective and should be used in conjunction with objective, functional and clinical measures of knee function.

An objective measure that is widely used to measure knee function is a patient’s time since surgery. The current goal is to return patients to unrestricted sports activities within six months (Keays et al., 2000; Shelbourne & Nitz, 1990; Di Stasi et al., 2013). In a systematic review conducted by Harris and colleagues (2014), 57% of the ACLR rehabilitation studies used the time since surgery as their only criterion for return to sports and only 10% provided some measurable, objective criteria that patients had to achieve before resuming unrestricted athletics. These proportions are alarmingly high considering that the time since surgery is a poor criterion as many individuals fail functional tests at six months (Barber-Westin & Noyes, 2011). Alternative objective evaluations of knee function have been developed and could be used in conjunction with time since surgery but, unfortunately, are not frequently used.

These objective evaluations include the isokinetic knee strength (Keays et al., 2000; Mattacola et al., 2002), single-leg vertical hop (Gustavsson et al., 2006), single-leg horizontal hop (Gustavsson et al.,
drop vertical jump (Ford et al., 2003), and agility tests (Myer et al., 2006) with the most commonly used tests being the isokinetic knee strength and the single-leg horizontal hop tests (Myer et al., 2006; Shaw et al., 2004; van Grinsven et al., 2010; Werstine, 2009). However, these maximal effort tests place high demands on the ACL-reconstructed knee, something that is contraindicated early in rehabilitation (Cascio et al., 2004; Lahav & Burks, 2005). As a result, the knee strength and maximal hop tests can only be evaluated 3 months after surgery and by that time, if the rehabilitation is not going as planned, the patient’s return to unrestricted athletics may be delayed for up to a year or longer. Determining a patient’s readiness to perform more demanding movements is important; however, since maximal effort tests cannot be performed early in the rehabilitation process due to their high demands on the ACL, a less demanding, objective test that quantitatively measures functional ability is required in the early stages of rehabilitation to gauge a patient’s progression.

The step-up-and-over (SUAO) test is a functional test that simulates stair climbing and is less demanding than many proposed knee function tests. It involves stepping on and over a single step and requires concentric knee extensor control to step up and eccentric knee extensor control to step down (Bailey & Costigan, 2015; Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004). Previous studies used a force plate to record the ground reaction forces during the stepping and the resulting measures differed between an ACL-intact and an ACL-injured population (Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004). For many clinics, the size, expense, and expertise to use a force plate and its associated equipment are not readily available and may be barriers to using the SUAO test. However, Bailey and Costigan (2015) investigated using an accelerometer instead of a force plate in the SUAO test to simplify the test and decrease its expense. They found that the variables typically extracted from the force plate data: lift acceleration, impact acceleration, and movement time were highly correlated with those same measures obtained using an accelerometer. Performing the SUAO test with an accelerometer could be clinically relevant as it is an easy, inexpensive alternative and requires low demands on the knee which could be used to measure knee function throughout a patient’s rehabilitation. Therefore, our purpose was
to determine whether the variables extracted from the accelerometer-based SUAO test throughout the rehabilitation process could shed some light on patient progress. To accomplish this the SUAO measures were tracked from after surgery to 6-months post-surgery along with the subjective assessment of knee function using the ACL-QoL questionnaire.

3.2 Procedure

3.2.1 Participants

Twelve ACL deficient patients (age: 32 ± 12 y; mass: 68 ± 10 kg; height: 1.76 ± 0.14 m) were recruited from a local surgeon’s patient list. Apart from their ACL injury, at the time of surgery the ACLR group was free from any other current lower limb and back injuries. The study was approved by the University’s Research Ethics Board and all participants signed a letter of informed consent (Appendix A).

3.2.2 Questionnaires

Following informed consent, the participants completed the Physical Activities Readiness Questionnaire Plus (PAR-Q+) (Appendix B) to screen for any underlying health conditions. To track their progress during rehabilitation, participants completed the Anterior Cruciate Ligament Quality of Life questionnaire (ACL-QoL) (Appendix C) which was administered electronically once a month to self-assess their knee function and pain-related fear. The shortened version of the Tampa Scale for Kinesiophobia (TSK-11) (Appendix G) was also administered electronically once a month to assess the patient’s fear of re-injury (see Chapter 5). The dates displayed in Appendix E reflect the days in which each participant completed the questionnaires. One participant was dropped as they only completed the questionnaire once, reducing the sample size for the ACL-QoL and TSK-11 (n = 11). After each testing session, the patients rated the most amount of pain they felt throughout the test on a Pain Visual Analog scale ranging from 0-100 with 0 indicating no pain and 100 indicating the most amount of pain they ever felt (see Chapter 5). All questionnaires were coded to ensure participant privacy, and once completed, were locked in a secure location.
3.2.3 Protocol

Upon arrival at the clinic, the participants performed a general warm-up consisting of 3 minutes of cycling, walking and guided stretching exercises for the hip, knee and ankle. Following this, the participants were instructed on the testing procedure, were provided with a demonstration of what was expected during testing and were given the chance to practice the motion required for the SUAO test. The SUAO was performed on a level floor with a 310mm high box. Participants stood behind the box, they then stepped up onto the box with their lead leg, carried their body and trail leg over the box, and landed with the trail leg contacting the floor on the other side of the box (Bailey & Costigan, 2015; Chmielewski et al., 2002; Mattacola et al., 2004). The participant then stepped down from the box and was instructed to remain still until given further instructions. Participants were asked to complete the SUAO test at a self-selected, comfortable pace, which was less effortful than the maximal stepping rate used by previous researchers and we felt increased the test’s safety and reduced the fear of re-injury. The SUAO test was repeated five times with each leg and the order of the ten trials was completely randomized. This procedure was repeated at every physiotherapy clinic visit until the participant reached 6-months post-surgery or was cleared by their physiotherapist to return to unrestricted physical activities (last day of testing: 142 ± 36 days from surgery). Two participants (S03 and S08) were tested at a neutral location as they did not attend physical therapy treatments. Two other participants (S07 and S09) withdrew from testing prior to being cleared by their physiotherapist because they sustained either a second lower-limb or a back injury.

3.2.4 Instrumentation

An inertial measurement unit (IMU) (X-IMU, x-io Technologies, UK), containing a triaxial accelerometer, gyroscope, and magnetometer was used to estimate the acceleration of center of mass (Mizuike et al., 2009; Moe-Nilssen, 1998). The IMU was secured with a Velcro strap over the spinous process of the L3 vertebra as an estimate of the center of mass location (Bailey & Costigan, 2015; Moe-Nilssen, 1998). The L3 vertebra of each participant was located by palpation. Bailey & Costigan (2015) found that an accelerometer returns SUAO measures comparable to the those obtained from a force plate
when it is strapped over the L3 vertebra. By placing a single IMU on the lower back either leg can be tested without having to move or reorient the IMU.

3.3 Analysis

The accelerations in all 3 directions were measured for each trial and the net acceleration was computed and used for further analysis. The body weight index (BWI), used to determine the SUAO test results, was computed by subtracting one g from the net accelerometer data. The variables of lift and impact index were extracted from the BWI curve using a custom Matlab program (R2016b, The MathWorks Inc., Natick, MA, USA). The lift acceleration is the peak value of the BWI curve during the up-phase of the step and the impact acceleration is the peak value during the down-phase of the step (Figure 3.1). The lift and impact indices characterize the concentric and eccentric control of the lead leg’s knee at the SUAO test’s lift and impact phases, respectively. The lift indices and impact indices were averaged over five trials for each leg in each participant to obtain one value per measure for both the ACLR affected leg and the ACLR unaffected leg per visit (see Appendix D).

The limb symmetries, calculated using the trial averages, were calculated by dividing the affected leg’s score by the unaffected leg’s score. Limb symmetry measures were calculated for the lift acceleration and the impact acceleration creating two new variables: lift symmetry and impact symmetry. For these variables a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetric. A study conducted by Bailey & Costigan (2015) found that a control group’s medians for the lift symmetry and impact symmetry scores were 0.97 ± 0.17 and 1.02 ± 0.16 respectively indicating that scores within this range are considered normal. To characterize the rate of change (improvement) in knee function during the rehabilitation period, a line of best fit was computed for the lift and impact symmetry measures and were calculated for each participant separately using a linear regression analysis (Table 3.1, Eq. 1).

Equation 3-1 Linear Regression Analysis

\[
y = ax + b
\]
where $y$ is the symmetry value, $a$ is the slope, $x$ is the days since surgery and $b$ is the intercept. Of interest from the regressions is the slope of the line of best fit, the value of $x$. The slope reflects the participant’s improvement over time and, therefore, should progress from some asymmetry score toward a score of 1.0, typically a negative line of progression.

With the regression coefficients computed for each participant, the projected time to reach perfect symmetry ($y = 1.0$) was calculated by setting $y$ to 1.0 (perfect symmetry) and computing $x$ (days since surgery). The expectation was that perfect symmetry ($y=1.0$) would be achieved when participants were released from their rehabilitation programs at around 6 months ($x=180$ days since surgery). Note that since there are 2 regression equations, one for the change in lift symmetry and another for the change in impact symmetry, there are two estimates of the time to perfect symmetry.

The scores for the ACL-QoL range from 1-10 with 1 indicating no issues and 10 indicating severe pain, weakness, or poor function. The final score is calculated by taking the mean score and dividing by ten to give a range of scores between 0.1-1.0. The ACL-QoL is a subjective measure of an individual’s knee function and a negative line of progression over time indicates improvement (decreasing pain and weakness and increasing function).

All statistical tests were performed using SPSS (V20, IBM Corporation, Armonk, NY, USA). Pearson’s correlation analyses were performed to determine the relationship between the ACL-QoL and the lift and impact symmetries. The significance threshold for all statistical tests was set at $P < .05$.

### 3.4 Results

The lift and impact indices for each participant can be found in Appendix D. The lines of progression for the lift symmetries of all participants can be found in Figure 3.2 and the lines of progression for the impact symmetries in Figure 3.3. As shown in Figures 3.2 and 3.3, the lift and impact symmetries are progressing towards perfect symmetry (1.0) for all participants except S09 and S13. These two participants moved away from perfect symmetry, indicating that they were getting increasingly asymmetric as time passed. The last testing day values for each participant displayed in Figures 3.2 and 3.3 were
calculated based on their lines of progression. These values represent a projected final value had each participant progressed perfectly based on their lines of progression. The values for the lines of progression for the lift and impact symmetries and the ACL-QoL are displayed in Table 3.1. All participants except S13 reported improvements in knee function as their ACL-QoL scores improved over time and all participants who attended physical therapy treatments were cleared by their physiotherapist to return to unrestricted athletics.

The last testing day for each participant, which was close to their date of release from rehabilitation, and their projected day to reach perfect symmetry, using both the lift and impact symmetry data, are displayed in Table 3.1. S09 and S13 do not have projected times to perfect symmetry as their results showed they were moving away from perfect symmetry over time. The average projected time to reach perfect symmetry was 376 days (SD: 282 days, Max: 1102 days, Min: 131 days) and 222 days (SD: 106 days, Max: 456 days, Min: 82 days) after their surgery day using the lift and impact symmetry lines of progression respectively. Two participants did not complete clinical physical therapy treatments. S03 underwent physiotherapy treatments for the first two months after surgery and continued their rehabilitation program at home thereafter. Although their eccentric control of their lower limb measured with the impact symmetry was projected to reach perfect symmetry prior to their last testing day, their concentric control measured with the lift symmetry was projected to reach perfect symmetry 360 days after the last testing day. On the other hand, S08 did not seek any treatment post-surgery and was projected to reach perfect symmetry 907 and 261 days after the last testing day for the lift and impact symmetries, respectively.

There is a moderate correlation between the line of progression of the lift symmetry and the impact symmetry \( r = .605, P < .05 \). There was no correlation found between the line of progression of the lift or impact symmetry and the ACL-QoL (Table 3.2). The scores for the ACL-QoL for each participant can be found in Appendix E.
Figure 3-1. Example of the SUAO test. The body weight index from the IMU was calculated by subtracting 1 g. Also displayed are the Lift Acceleration (L), and Impact Acceleration (I).
Figure 3-2. Lines of progression for the Lift Symmetry for all participants. Displayed are the computed lines of progression using a linear regression plotted from their first testing day and a computed last day of testing as measured from their surgery day.
Figure 3-3. Lines of progression for the Impact Symmetries for all participants. Displayed are the computed lines of progression using a linear regression plotted with their first testing day score and a computed and last day of testing as measured from their surgery day.
Table 3-1. Lines of progression for the lift and impact symmetry, ACL-QoL, the last testing day and the projected lift and impact symmetry days.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Slope Lift Sym. (x1000)</th>
<th>Slope Impact Sym. (x1000)</th>
<th>Slope ACL-QoL (x1000)</th>
<th>Last testing day</th>
<th>Projected Lift sym. day</th>
<th>Projected Impact sym. day</th>
</tr>
</thead>
<tbody>
<tr>
<td>S01</td>
<td>-3.5</td>
<td>-4.1</td>
<td>0.7</td>
<td>178</td>
<td>280</td>
<td>241</td>
</tr>
<tr>
<td>S02</td>
<td>-3.4</td>
<td>-4.6</td>
<td>-5.0</td>
<td>130</td>
<td>185</td>
<td>82</td>
</tr>
<tr>
<td>S03</td>
<td>-2.1</td>
<td>-5.2</td>
<td>-0.7</td>
<td>184</td>
<td>544</td>
<td>154</td>
</tr>
<tr>
<td>S04</td>
<td>-2.4</td>
<td>-14.7</td>
<td>-2.1</td>
<td>151</td>
<td>395</td>
<td>155</td>
</tr>
<tr>
<td>S05</td>
<td>-5.3</td>
<td>-12.1</td>
<td>-1.5</td>
<td>174</td>
<td>256</td>
<td>174</td>
</tr>
<tr>
<td>S06</td>
<td>-2.9</td>
<td>-38.8</td>
<td>-2.1</td>
<td>120</td>
<td>397</td>
<td>179</td>
</tr>
<tr>
<td>S07</td>
<td>-7.7</td>
<td>-6.7</td>
<td>-0.5</td>
<td>124</td>
<td>227</td>
<td>328</td>
</tr>
<tr>
<td>S08</td>
<td>-0.9</td>
<td>-3.8</td>
<td>-1.5</td>
<td>195</td>
<td>1102</td>
<td>456</td>
</tr>
<tr>
<td>S09</td>
<td>14.9</td>
<td>14.7</td>
<td>n/a*</td>
<td>71</td>
<td>n/a†</td>
<td>n/a†</td>
</tr>
<tr>
<td>S10</td>
<td>-6.2</td>
<td>-11.3</td>
<td>-1.2</td>
<td>139</td>
<td>131</td>
<td>251</td>
</tr>
<tr>
<td>S11</td>
<td>-5.1</td>
<td>-12.8</td>
<td>-1.5</td>
<td>110</td>
<td>244</td>
<td>205</td>
</tr>
<tr>
<td>S13</td>
<td>4.7</td>
<td>0.7</td>
<td>1.0</td>
<td>122</td>
<td>n/a†</td>
<td>n/a†</td>
</tr>
<tr>
<td>Average</td>
<td>-1.7</td>
<td>-8.2</td>
<td>-1.3</td>
<td>142</td>
<td>376</td>
<td>223</td>
</tr>
<tr>
<td>SD</td>
<td>6.1</td>
<td>12.4</td>
<td>1.6</td>
<td>36</td>
<td>282</td>
<td>106</td>
</tr>
</tbody>
</table>

Sym. = symmetry.
SD = standard deviation.

* Only one ACL-QoL questionnaire was answered resulting in no line of progression.
† Positive lines of progression increasing away from 1.0 skewing the results of the projected lift and impact symmetries. See Figures 4.2 and 4.3 for the lines of progression of these participants.

Table 3-2. Correlations (Pearson’s r) between the lines of progression of the Lift and Impact Symmetries (N=12) and the ACL-QoL

<table>
<thead>
<tr>
<th></th>
<th>slope LIFT</th>
<th>slope IMP</th>
<th>slope ACL-QoL</th>
</tr>
</thead>
<tbody>
<tr>
<td>slope LIFT</td>
<td>1</td>
<td>.605*</td>
<td>.289†</td>
</tr>
<tr>
<td>slope IMPACT</td>
<td>.605*</td>
<td>1</td>
<td>.282†</td>
</tr>
<tr>
<td>slope ACL-QoL</td>
<td>.289†</td>
<td>.282†</td>
<td>1</td>
</tr>
</tbody>
</table>

* Correlation is significant at the 0.05 level (2-tailed).
† N=11

3.5 Discussion

The main purpose of this study was to determine whether the SUAO test could track an ACLR participant’s progress throughout rehabilitation and if that progress correlated to the participant’s subjective assessment of their knee function measured using the ACL-QoL questionnaire. A positive progression is
defined as a change in symmetry score from asymmetric to symmetric as it approaches 1.0, perfect symmetry.

The lift and impact symmetries are related (Pearson’s $r = 0.6$) and the mean of the group for both symmetries displays a negative line of progression however, as shown in Table 3.1, using the equations for the lift and impact symmetries there is difference in the predicted time at which a participant would reach perfect symmetry. The day to reach symmetry that is the furthest from surgery would be the more conservative criterion to consider during the physiotherapy treatment process as asymmetries increase the risk of a second injury (Ford et al., 2003; Hewett et al., 2005; Thomeé et al., 2012). However, this test should not be solely used to determine readiness to return to unrestricted athletics due to its submaximal nature. A combination of sub-maximal effort tests and maximal effort tests such as the single leg hop test should be used as return to sport criteria. Interestingly, the average time to reach perfect symmetry was smallest for the impact symmetries which measures the eccentric control of the knee extensors. These results are in contradiction with other studies that suggest that although rehabilitation protocols emphasize knee extensor training both concentrically and eccentrically, the concentric control is regained more quickly (Hiemstra et al., 2000; 2007) indicating that further research is required since a small sample size was used for this study.

A negative line of progression for the ACL-QoL indicates a positive increase in subjective knee function. All participants exhibited a positive progression in their opinion of their knee function through rehabilitation with the exception of one participant. This participant showed a positive line of progression, indicating a worsening of their subjective knee function over time. However, their scores of 2.6, 2.1, and 2.3 for the three questionnaires answered are skewed by the increase in their last score which might reflect a single bad day rather than a consistent worsening trend.

The patient’s opinion of their knee function is important as it provides individuals confidence in being able to return to their pre-injury levels of activity. However, while the lines of progression for the symmetry indices and ACL-QOL were both negative (Pearson’s $r = 0.29$, $p > 0.05$), there was no correlation
between the ACL-QoL and either the lift or impact symmetries. Examining the differences in lines of progression between these variables shows that the participant’s lines of progression for ACL-QoL are much flatter due to both the range of scores possible and rate of improvement. This questionnaire was only answered once a week which may account for the smaller progression. However, the ACL-QoL is a subjective questionnaire and the lack of a correlation with the objective measures obtained from the accelerometers suggest that this ACL-QoL questionnaire may not be an alternative to the SUAO test. The lift and impact symmetries offer a different, objective assessment of an individual’s progression through rehabilitation.

The difference in projected limb symmetries for each participant may be attributed to the difference in rehabilitation methods and protocols each participant chose to undertake. There is a lack in agreement regarding the specific number of physiotherapy treatments each individual requires throughout ACLR rehabilitation (Bach, Tradonsky, Bojchuk, Levy, Bush-Joseph, & Khan, 1998; DeCarlo, Shelbourne, McCarroll, & Rettig, 1992; DeCarlo and Sell 1997; O’Connor & Jackson, 2001). For example, S08 did not attend physiotherapy treatments and, as a result, their projected times to perfect symmetry are significantly greater than any other participant. According to Ageberg and colleagues (2001), although muscular strength and functional performance can be restored with both an at home program and supervised physical therapy visits, the sensory system for maintenance of postural control may not fully recover with a home-based program. Additionally, S03 only partook in physiotherapy treatments for the first 2 months and proceeded to continue their rehabilitation program at home. This participant had the second longest projected time to perfect symmetry. These increased projected times highlight the importance of having a supervised rehabilitation program and should be used to gauge a participant’s progression rather than readiness to return to unrestricted athletics. For those who do not have adequate health coverage for physiotherapy treatments throughout rehabilitation, a staggered approach in supervised visits with a registered physical therapist may be required. They might attend one physiotherapy clinic visit a month with a prescribed at
home program. This type of approach may help with improvements in performance progression throughout rehabilitation by providing the patient with consistent feedback on their knee function.

In addition, two participants were excluded from the projected symmetry days because of their increasingly asymmetrical limb symmetry scores. One of these participants injured their back early in their rehabilitation program (71-days post-surgery) which delayed their rehabilitation progress and may not have had adequate time to begin progressing during their rehabilitation. S13 also had increasingly asymmetrical scores through their recovery. This participant had previous ACL reconstructions on both knees prior to this surgery, which may have impeded their progress.

As mentioned previously, the lift and impact symmetries may offer an objective assessment of an individual’s progression throughout ACLR rehabilitation. However, the SUAO test does not assess a specific knee function suggesting that this test should be used in conjunction with other objective measures to fully evaluate an individual’s knee function throughout rehabilitation. This promising pilot study provides evidence that the SUAO test is a tool that may be used to evaluate an individual’s progression throughout their rehabilitation as it is a safe and quick dynamic assessment of low demand. The SUAO test only takes approximately 5 minutes to complete and when performed at a comfortable pace, it is a safer alternative to more high demand evaluations such as the single leg hop tests and can be performed in the early stages of rehabilitation. Further research should evaluate the use of the SUAO test in larger populations to determine its effectiveness in measuring ACLR progression through rehabilitation. The SUAO test may be used in conjunction with other objective assessments to help determine readiness to return to pre-injury level of physical activities as it can be used as both a sub-maximal and maximal effort test.

3.6 Conclusion

In conclusion, performance on the SUAO test throughout rehabilitation is not related to a patient’s opinion of their knee function and therefore may be used to track an individual’s progression through rehabilitation. The use of the SUAO test consistently throughout rehabilitation could provide a new option
that is practical for clinicians to evaluate the progression of each individual undergoing ACLR rehabilitation in conjunction with other objective measures.
Chapter 4

Effects of pain and fear of re-injury on Step-up-and-over performance in ACLR patients through rehabilitation

4.1 Introduction

The purpose of surgically repairing a torn anterior cruciate ligament (ACL) is to restore normal knee function including the ability to perform pre-injury activities. However, 24% of individuals who have an ACL surgically repaired choose not to return to their pre-injury levels of activity and report their fear of re-injury as the main reason (Kvist et al., 2005, Tripp, Stanish, Ebel-Lam, Brewer, & Birchard, 2007). In some cases, athletes return to the same sport but at a reduced level of competition, whereas others return to a different sport while some leave sport altogether. Fear of movement/re-injury tends to decrease with increasing time from surgery and is inversely related to joint function (Chmielewski et al., 2008); the better you move the less fearful you are of movement. However, the inability to overcome this fear of movement/re-injury delays the ACL-reconstructed (ACLR) patients’ improvement during rehabilitation, increasing their recovery time which in turn can delay their return to activity (Kvist et al., 2005; Mainwaring, 1999).

As with the fear of re-injury, pain-related fear and pain itself are other factors that influence an individual’s choice to return to their pre-injury level of activity (Swinkels-Meewisse, Roelofs, Oostendorp, Verbeek, & Vlaeyen, 2006). Complications from injury or surgery such as anterior knee pain hinder rehabilitation and a delay in rehabilitation could result in a loss of range of motion, increased anterior knee sensitivity to pain and possibly the need for follow-up surgery (Kartus, Magnusson, Stenert, Brandsson, Eriksson, & Karlsson, 1999). Those who focus on pain sensations are unable to effectively use coping strategies which may increase their future disability (Sullivan et al., 1998, 2002). Additionally, the sensation of pain has been shown to decrease the recovery of muscular strength in the affected leg of ACLR patients (Natri et al., 1996). Similar to fear of re-injury, pain can increase the time needed to recover full knee
function and if these factors are not considered throughout the rehabilitation process, patients can be cleared to return to full activity without being truly ready.

The current goal of rehabilitation is to return patients to unrestricted sports activities within six months (Keays et al., 2000; Shelbourne & Nitz, 1990). Typically, patients are released after six months of rehabilitation solely based on the time since surgery and in some cases must pass an ‘exit’ test before being cleared to return to unrestricted sports activities. However, after six months fewer than half of the patients pass the selected exit tests (Thomeé et al., 2012), which, in part, may explain the rate of non-return to sport. These tests often include limb symmetry measures using either isokinetic knee strength testing or the single-leg horizontal hop test requiring the affected limb to have a performance of at least 85% compared to the unaffected limb to pass (Myer et al., 2006; Shaw et al., 2004; van Grinsven et al., 2010; Werstine, 2009). These two tests are the most commonly used tests (Myer et al., 2006; Shaw et al., 2004; van Grinsven et al., 2010) and, although valid and reliable, both require a maximal effort from the ACL-reconstructed knee. This level of effort is contraindicated early in rehabilitation (Cascio et al., 2004; Lahav & Burks, 2005) and so these tests are not used throughout the rehabilitation program but only as exit tests. The high demands placed on the knee by these tests could result in knee pain or trigger an individual’s fear of re-injury, either of which could limit an individual’s ability to perform the test which may confound the patient’s performance thereby limiting the tests’ ability to determine the patient’s readiness to be released. Thomeé and colleagues (2011) suggested that the current functional tests are either not demanding enough or not sensitive enough to identify differences between injured and non-injured limbs and felt that new criteria were required to evaluate knee function before allowing athletes to safely return to sports after ACLR (Thomeé, Kaplan, Kvist, Myklebust, Risberg, Theisen, Tsepis, Werner, Wondrasch, & Witvrouw, 2011).

If maximal effort tests cannot be performed due to their high demands, sub-maximal effort tests must be used to evaluate knee function in the early stages of rehabilitation to identify any issues in progression that may arise and change the course of treatment accordingly. The step-up-and-over (SUAO) test is a sub-maximal effort test that differentiates between the affected and unaffected legs of patients with
ACLR, and between ACL-deficient patients and ACL-intact populations (Chmielewski et al., 2002; Lin et al., 2010; Mattacola et al., 2004). As with many knee function tests, including muscle strength testing and the single-leg hop for distance, the main outcome from the SUAO test is the ratio of performance between the affected and unaffected legs and it is expected that at release the performance of the affected leg be better than 85% of the unaffected leg and in some cases equal to the affected leg (100%) (Thomeé et al, 2011). Bailey and Costigan (2015) investigated the use of the SUAO test performed at a comfortable pace, rather than a maximal pace used in previous research, and found similar results between the variables obtained from a force plate and those obtained from an accelerometer. At a slower pace, this test can be used throughout rehabilitation to assess the limb symmetry performance of ACLR patients, enabling clinicians to track an individual’s progress and allow them to alter a patient’s course of treatment if needed. In this pilot study, we hypothesize that pain will be associated with more asymmetrical (further from 100%, or 1.0 as a ratio) SUAO scores and, since the test asks the participant to step at a comfortable, self-selected pace, fear will not be correlated with SUAO scores.

4.2 Methods

Twelve participants (7 females and 5 males) were recruited from a surgeon’s patient list and all had had an ACL reconstruction. Mean patient age at the time of surgery was 32 (Range: 16-55) years. The mean time from injury until surgery was 14 (Range: 3-52) months. Five participants received a hamstring graft and seven received a bone-to-bone patella tendon graft. Besides their reconstructed ACL, participants were free from any other back or lower body injury at the time of surgery. Prior to beginning the study, each participant completed the Physical Activity Readiness Questionnaire Plus (PAR-Q+) to screen for any underlying health conditions and signed a letter of informed consent.

Once a month after surgery, participants completed a shortened version of the Tampa Scale for Kinesiophobia (TSK-11) administered electronically to subjectively assess their fear of re-injuring their knee (Appendix G). The TSK-11 was completed each month until participants were cleared by their physical therapist to return to unrestricted physical activities. The dates displayed in Appendix E reflect the
days in which each participant completed the questionnaire. The 11 items of the TSK-11 have four response options: “strongly disagree”, which scores 1 point, and “strongly agree”, which scores 4 points. The total sum score is calculated and can range from 11 to 44. A high score indicates a strong fear of movement/re-injury. On each testing day, at the completion of the final trial, participants rated the highest pain they felt throughout the test on a Pain Visual Analog Scale, where 0 was no pain and 100 was the worst pain they ever felt (Appendix H). The Pain Visual Analog scale began being administered after the study had begun reducing the sample size for the pain scores (n = 85).

At each physical therapy clinic visit participants performed the Step-Up-and-Over (SUAO) test. Before the test, participants warmed up on a stationary bicycle for 3 minutes and performed dynamic stretching exercises of the hip, knee and ankle. Before beginning the Step-Up-and-Over (SUAO) test, an inertial measurement unit (IMU) (IMUx, x-io Technologies, UK) was secured to a Velcro strap placed at their lower back to approximate the center of mass location. The IMU recorded the 3-dimensional accelerations that later were combined to give the net acceleration. Once the participant was comfortable performing the test, they stood behind a 12-inch box and then stepped on the box with their lead leg, swung their trail leg over the box, landed on the other side of the box and stepped down. Each participant completed the SUAO test 5 times on each leg and the order of the 10 trials was randomized. The test was completed at a self-selected pace.

The SUAO test returns the variables of lift acceleration and impact acceleration for each trial. The lift acceleration characterizes the concentric control of the lead leg’s knee extensors and the impact acceleration characterizes the eccentric control of the lead leg’s knee extensors. Once the net acceleration was computed, 1g was subtracted to remove the acceleration due to gravity. The lift acceleration is the peak net acceleration during the up-phase of the test and the impact acceleration is the peak net acceleration during the down-phase. The lift and impact indices were then averaged across the trials for both the affected and unaffected leg. After averaging, a symmetry score was calculated by dividing the affected leg’s score by the unaffected leg’s score. Limb symmetries were calculated for both the lift acceleration and the impact
acceleration giving two new variables: lift symmetry and impact symmetry. A symmetry score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetric.

Separate linear regression models were determined for lift symmetry, impact symmetry, and fear of re-injury all regressed against time since surgery and a power model was determined for the pain scores as it showed an exponential decay in scores occurring in the first 3 months with a plateau thereafter. The beginning of the plateau for each participant was determined by calculating the first point in which the line of progression of the curve became zero. These four models were determined for each participant. Correlations examined the relationship of the lines of progression among the four variables. The influence of pain and fear was examined on each individual’s rehabilitation progress.

In an additional analysis, the residuals from the regression models of all four variables for each participant were calculated to remove the effect of time. The influence of pain and fear on an individual’s performance was examined on each testing day. Correlations examined the relationships among the variables after removing the time trend.

4.3 Results

The best fit for the variables was determined by using the smallest residuals. As a result, a linear regression was applied to the lift symmetry, impact symmetry and fear of re-injury variables and a power regression was applied to the pain scores. The curve profiles for all four variables for a select participant’s progression through rehabilitation are displayed in Figure 4.1. The regression models for each participant are given in Appendix I.

A negative line of progression for the lift and impact symmetries indicates that the affected leg is becoming increasingly similar to the unaffected leg and a positive line of progression indicates that the affected leg is becoming increasingly dissimilar to the unaffected leg. Two participants had positive lines of progression suggesting their limbs became increasingly asymmetrical with time. A negative line of progression for the pain scores over time indicates a decrease in pain during the rehabilitation process. S02 was the only participant who exhibited no change in their pain score throughout rehabilitation, denoted by
a line of progression of zero. All other participants had a negative line of progression seen by an exponential decrease in scores with a plateau (a low point) occurring approximately 96-days post-surgery (SD= 36.4). An example of the pain line of progression can be seen in Figure 4.1. Since the pain scores were fitted with a power curve, more negative lines of progression indicate a faster decrease in pain over time.

Additionally, for fear of movement/re-injury a negative line of progression towards 1.1, the lowest possible score, indicates a decrease in fear. Two participants, S02 and S09 did not experience a change in fear through rehabilitation as denoted by a line of progression of zero. On the other hand, three participants had a positive line of progression (see Appendix I) suggesting an increase in fear of movement/re-injury as their rehabilitation progressed.

As expected, the lift and impact symmetry lines of progression were correlated with each other \( r = 0.603, P < 0.05 \) suggesting an improvement in both concentric and eccentric knee function during rehabilitation. The fear of re-injury (TSK-11) line of progression was correlated with the impact symmetry line of progression \( r = .591, P < 0.05 \) suggesting that as knee eccentric function improved the fear of injury decreased. The line of progression of the pain scores was negatively correlated with the lift symmetry line of progression \( r = -.582, P < 0.05 \) indicating that as pain decreased more rapidly, the impact symmetry line of progression became more positive suggesting a slower progression (Figure 3.2).

After removing the effect of time there was a weak correlation between pain and lift symmetry \( r = .219, P < 0.05 \) and between pain and impact symmetry \( r = .333, P < 0.01 \) indicating that on each testing day, the higher the pain score the less symmetrical the lift and impact scores were for each individual. There was no relationship between fear of re-injury (TSK-11) and either lift or impact symmetry (Ps > 0.05).
Figure 4-1. An example of a participant’s pain scores, fear or re-injury scores, lift symmetry, and impact symmetry scores according to days from surgery. The Pain Visual Analog Scale scores were reduced from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled to the other variables by dividing each score by 10 to give a range from 1.1-4.4; 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring the knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure 4-2. Relationship between the lines of progression of the pain scores and the lift symmetry scores

4.4 Discussion

The purpose of this study was to examine the relationship between pain and fear of re-injury on the variables obtained from the SUAO test measured throughout rehabilitation. In a positive progression through rehabilitation, a change in symmetry score from asymmetric to symmetric (approaching 1.0), a decrease in pain (approach 0.0) and a decrease in fear of re-injury (approach 1.1) would be expected. As mentioned, only two participants became increasingly asymmetrical through rehabilitation denoted as a symmetry score increasing away from 1.0. All participants exhibited a decrease in pain except one who experienced no change in pain through rehabilitation. Those with a decrease in pain experienced a plateau in pain occurring at approximately 96-days post-surgery. Three participants experienced an increase in fear of re-injury through rehabilitation and two experienced no change in fear whereas all other participants experienced a decrease in fear of re-injury as rehabilitation progressed.
As hypothesized, a correlation was found between impact symmetry and pain; however, this correlation is negative suggesting that as an individual’s pain levels drop more quickly (becomes more negative), their eccentric control of their knee measured with the impact symmetry is more asymmetrical over time or progresses more slowly. However, as shown in Figure 4.2, the participant who experienced the most negative pain line of progression (-5.3) and experienced a decrease in symmetry, as shown by the positive line of progression appears to have skewed the data. As a result, this relationship needs to be further investigated with a larger population.

Since all pain lines of progression with the exception of one participant were negative, Figure 4.1 demonstrates an example of the general trend that occurs through rehabilitation. A large decrease of pain with time occurred for all participants and suggests that the influence of pain on performance may only be dominant in the early stages of rehabilitation. However, if pain persists beyond the first three months, individuals are more likely to have delays in recovering their pre-injury levels in muscular strength (Kobayashi et al., 2004; Natri et al., 1996) possibly contributing to a decrease in knee function and in turn might increase an individual’s fear of re-injury. On day 122 post-surgery, S13 was still experiencing some pain and their limbs had become increasingly asymmetrical throughout rehabilitation for both the lift and impact symmetries suggesting a delay in recovery. On the other hand, S02 experienced no change in pain throughout their rehabilitation as displayed by a line of progression of zero.

The lines of progression for fear of re-injury were correlated with the lift symmetry line of progression highlighting the importance of targeting fear of re-injury early in rehabilitation to aid in improvements of the concentric control of the individual’s knee’s extensors as measured with the lift symmetry. Despite individuals regaining full knee function, fear of re-injury remains the main reason for approximately 1/4 of patients who chose not to return to their pre-injury levels of physical activities (Kvist et al., 2005). Those who are more fearful of re-injuring their knees are more likely to progress more slowly in regaining their pre-injury level of concentric control of their injured knee’s extensors. The results in this study are in agreement with a study by Lentz and colleagues (2014) who found a relation between increased
fear of re-injury and quadriceps weakness at 6 months and 1-year post-surgery indicating a relationship exists between progression and fear. However, S02 did not experience any change in fear and maintained a low level of fear of re-injury throughout their rehabilitation suggesting they may have had adequate coping mechanisms and strategies to maintain these low levels of fear throughout their rehabilitation. This participant’s lift and impact symmetries also improved throughout rehabilitation with a final symmetry score of 1.22 and 0.81 for the lift and impact symmetry respectively. Although this participant’s limbs were not perfectly symmetrical at release, they demonstrated an improvement from 1.46 and 1.15 for the lift and impact symmetries on their first testing day (48-days post-surgery). Physicians and physiotherapists should work with their patients on overcoming this fear throughout rehabilitation to ensure they are not fearful when returning to physical activities post ACLR rehabilitation.

Positive correlations were found between the residual pain scores and the residual lift and impact symmetries indicating that pain may negatively influence an individual’s performance during the SUAO test on any given day since symmetry scores are more asymmetrical with an increase in pain. This relationship has been seen by Sullivan and colleagues (2002) who found that individuals who were unable to cope with their pain experienced negative moods, increased pain and a reduction in the weights they were able to lift, suggesting that pain and the fear of pain influence daily performance. Since residual pain scores are related to the residual impact symmetry scores, the lift symmetry score may be the preferred measure to use to monitor knee performance during rehabilitation as it was not related to pain. Additionally, fear of re-injury was not related to either SUAO variables on the testing day.

Although the SUAO test was performed at a self-selected pace to reduce the effect of pain and fear of re-injury, pain may still have influenced an individual’s landing strategies. Individuals who report knee pain often report difficulties going down stairs but little to no difficulty going up stairs (Fairbank, Pynsent, van Poortvliet, & Phillips, 1984). Since the SUAO test mimics stair climbing, the landing portion of the test, which results in higher levels of pain, may result in a fear of pain and ultimately a fear of re-injuring the patient’s knee. However, the variables obtained from the SUAO test were not correlated with fear of re-
injury, suggesting this test is may be an alternative to more demanding knee function tests such as the single-leg, horizontal hop test in the early stages of rehabilitation to evaluate progression through rehabilitation. A self-selected and comfortable pace was used by each participant and that may have reduced the effect of fear of re-injury. This suggests that the SUAO test may be used as soon as the patient has enough range of motion to step up on the box and then step down. The SUAO test is a quick test of ACLR performance that should be used to evaluate each individual’s progression through rehabilitation.

Further studies should investigate the effect of pain and its influence on an individual’s progression through rehabilitation. In conclusion, this promising pilot study has shown that the mild and moderate correlations between pain and the lift and impact symmetries suggest that when measuring the variables obtained from the SUAO test, pain should also be recorded as there appears to be an influence on the SUAO scores.
Chapter 5

General Discussion

The results from Chapters 4 and 5 suggest that the SUAO test, executed using an accelerometer, is a promising objective and practical method for clinicians to administer during ACLR rehabilitation. Chapter 4 provides the support for using an accelerometer to track an individual’s performance progress through the stages of rehabilitation using a functional test requiring low demands on the knee. Using an accelerometer for the SUAO test also may allow clinicians to administer the test efficiently and provides more information about a patient’s knee function as it is not related to their subjective assessment of their own knee function using the ACL-QoL.

While Chapter 4 suggests that an accelerometer can track an individual with an ACL reconstruction through rehabilitation, Chapter 5 evaluated the effects of fear of re-injury and pain on the daily performance of each individual on the SUAO test. The results highlighted the importance of tracking an individual’s pain levels throughout rehabilitation as they may influence the variables measured using the SUAO test on a daily basis. The patient’s fear of re-injury was related to the progression of impact symmetry suggesting that as fear of re-injury abated, the individual’s impact symmetry improved. However, fear did not influence the daily performance on the test. Combining the results from Chapters 4 and 5, the SUAO test is an objective and practical measure applicable in a clinical setting that effectively measures a patient’s progress without fear of re-injury impeding the results.

The SUAO test provides more information about an individual’s knee function through rehabilitation and effectively measures ACLR patients’ progress as seen in Chapter 4. The time at which participants were released from rehabilitation were not in agreement with the projected days to symmetry calculated in Chapter 4; however, these projected times should be used as guidelines to gauge a participant’s progression as opposed to a release criterion since many studies suggest an 85% limb symmetry score as being adequate to return to unrestricted athletics (Myer et al., 2006; Shaw et al., 2004; van Grinsven et al.,
2010; Werstine, 2009). The average day the patients were released from physical therapy was 142-days post-surgery and the average projected time to symmetry was 376 days and 222 days after their reconstruction surgery for the lift and impact symmetry respectively. While previous rehabilitation programs began with immobilization of the affected leg to protect the graft, current accelerated programs begin weight bearing and passive range of motion immediately post-surgery (Carol et al., 1992). The accelerated rehabilitation program aims to release patients in 6 months to unrestricted physical activities. However, as seen by the average release date for these participants, it appears that individuals are being released around 4-months post-surgery. All patients who attended supervised physical therapy treatments were released by their physiotherapists suggesting that the release criteria used for these patients indicated they were ready to return to unrestricted athletics. It is however unclear if these individuals are ready to return to unrestricted physical activity at this time since the results from the SUAO test indicate that many do not have symmetrical limbs upon release and up to 30% of individuals with an ACL reconstruction have a repeat injury within the first two years after release (Paterno et al., 2014; Webster et al., 2014). The high number of repeat injuries suggests that future studies investigating the progression of patients with the SUAO test should measure the performance of patients with current exit tests after 3 months to provide more information about a participant’s progress after ACLR.

Objective measures are important for evaluated ACLR patients’ knee function post-surgery as many believe that their knees are healed and highly functional when in fact, this may not be the case (Harter et al., 1988; Kocher et al., 2004; Myer et al., 2008; Risberg et al., 1999; Ross et al., 2002). Participant S02 participated in competitive sports and after 4 months chose to not to attend supervised physical therapy clinic visits. As seen in Chapter 5, S02 had initial low pain and fear scores and no change in pain or fear of re-injury throughout their rehabilitation. Despite their assessment of their own knee function being near normal with the use of the ACL-QoL at the time they terminated treatment, their projected time to symmetry was 55 days after their last testing day for the lift symmetry suggesting they still required some supervised physical therapy to increase symmetry of their limbs. Asymmetrical limbs are the main causes of
individuals sustaining a subsequent ACL tear (De Vita et al., 1998; Kaur et al., 2016; Noehren et al., 2013; Paterno et al., 2010; Salmon et al., 2005; Di Stasi et al., 2013; Wright et al., 2007) highlighting the importance to test different areas of knee function using objective measures such as limb symmetry since subjectively, this participant believed to be fully recovered and may not have been.

However, using only measures of symmetry may be problematic since symmetry scores hide details about how symmetry was achieved. The symmetry score is computed by dividing the lift or impact acceleration for the affected leg by the corresponding acceleration for the unaffected leg. Therefore, the same symmetry score can be achieved by having high scores on both legs or lows scores on both legs. When examining the lift and impact acceleration scores that compute the symmetry score, several different cases emerged. The most common case was ACLR patients who had a “high affected” score, where the affected leg lifted or impacted more forcefully than their unaffected leg. Patients who fit this case on any day may have had less control of their ACL-reconstructed knee. However, the lack of control may have gone unnoticed if their unaffected leg also had a ‘high unaffected’ score, leading to a symmetry score close to 1.0 since the two legs performed similarly. On the other hand, participants who had a “low affected” score, lifted or impacted less forcefully than their unaffected leg. These low cases suggest that these patients may have been being cautious. Again, the low score may have gone unnoticed if they also were cautious with their unaffected leg. For example, on day 118 post-surgery, S10 had a low affected and low unaffected score (0.999 and 0.9686, respectively) resulting in a perfect limb symmetry whereas on day 65 post-surgery, S09 had a score of 4.2892 and 4.9452 also resulting in perfect symmetry. These two cases, although the scores are highly different and may have been exhibiting different strategies to complete the test, the symmetry score is very similar highlighting the importance to use other objective measures to assess knee function.

In addition to variability within individuals resulting in perfect symmetry scores, variability also occurred within the same individual throughout their rehabilitation. For example, on day 45, participant S08 had a “low affected” lift acceleration score but a limb symmetry of 0.97, near perfect symmetry.
However, on the next testing day (56-days post-surgery) their lift symmetry score was 2.06 indicating the limbs were not symmetrical. On day 45, this individual exhibited less control of their unaffected leg when lifting up on the box generating this near perfect limb symmetry value and obtaining a “low affected” score. The variability in scores on a daily basis suggest that frequent testing of the SUAO test throughout rehabilitation is important to reduce any outliers which may result in skewing the line of progression.

Variability also occurred between different participants. The results for participant S08 show that some form of supervised rehabilitation is important for proper recovery. S08’s score on the ACL-QoL showed that they felt they improved during the testing period while at the same time their fear of re-injury increased. Also, their predicted dates to limb symmetry were 907 and 261 days after their last testing day (195-days post-surgery). S08 did not have adequate health coverage and did not attend physical therapy. The lack of supervised visits may have accounted for their slow recovery and their increase in fear of re-injury throughout their recovery. This highlights the importance of having clinicians and physiotherapists work with patients throughout rehabilitation to decrease this fear with behavior counselling and improve their knee function both subjectively and objectively to improve the proportion of patients that are able to safely return to their pre-injury levels of physical activity.

S13 was a particularly interesting participant as they had two previous reconstructions, one on each knee. This participant’s limbs became increasingly asymmetrical and their subjective knee function became worse throughout rehabilitation. This decrease in function both subjectively and objectively highlights the importance of using both objective and subjective evaluations to measure an individual’s knee function throughout rehabilitation and before release to unrestricted physical activities. Although this participant exhibited increasingly asymmetrical limbs seen through rehabilitation, they were released from physical therapy treatment 122-days after their surgery suggesting that other measures were used to determine their readiness to return to unrestricted physical activity. As a result, symmetry measures along with other release criteria need to be used in conjunction to evaluate an individual’s knee function and one measure cannot be solely used to evaluate a person’s function without the other.
Although it is important to consider symmetry measures as they are easy to calculate, objective and widely used measures for assessing return to physical activity readiness in patients with an ACL-reconstruction (Gustavsson et al., 2006; Myer et al., 2006; van Grinsven et al., 2010; Werstine, 2009; Wilk et al., 1994), these measures on their own may not provide enough information to release patients to unrestricted physical activities. The SUAO test requires one leg to control the movement through the step up and over portion of the test and problems with postural control could influence the result. The accelerometer used to measure the SUAO test measures accelerations in all 3 directions which could allow future studies to investigate postural stability using accelerations that would provide more information about knee function, increasing the value of the test. The SUAO test is quick to administer and its ability to be administered with the use of an accelerometer makes it easily portable and applicable in a clinical setting.

The results of Chapters 4 and 5 in this thesis come with some important limitations that may guide further research. The small population used for these studies had varying characteristics. These patients had a wide range in age (32 ± 12 y), mass (68 ± 10 kg), height (1.76 ± 0.14 m), different grafts, their health histories were unknown. The differences in their demographics may have led to different performances and it is unknown if these factors affect the SUAO test performance. Another limitation of these studies was the studies’ designs. Due to time constraint, a small population size was used and many variables that might have affected the SUAO performance could not be tested. For example, pre-operative strength, or the intensity of rehabilitation, or adherence to one’s rehabilitation program may have influenced an individual’s progression through their rehabilitation programs and should be investigated in future research.

In all, this thesis has contributed a promising new method for evaluating progression through rehabilitation with an easy, objective and quick test that is accessible to clinicians. Chapter 2 demonstrated that although many methods of evaluating ACLR patients’ knee function exist, none are objective, of low demand and inexpensive, which is required for a test to be integrated into clinic setting in the early stages of rehabilitation following an ACL reconstruction. Bailey and Costigan (2015) modified the test with an
inexpensive accelerometer and changed the movement speed to a comfortable pace allowing the SUAO test to track an individual’s progression through rehabilitation. This modified SUAO test was then used to assess the performance of ACLR patients through rehabilitation. The patient’s performance was not related to their subjective knee function (Chapter 4) or their fear of re-injury (Chapter 5), but it was related to their pain levels (Chapter 5). Together, Chapters 4 and 5 showed that the SUAO test is a clinically relevant method that is not affected by fear of re-injury and can be used to track an individual’s progress through rehabilitation. This discussion then described some of the current issues related to symmetry tests and variables that require further study. As a next step, clinicians should assess whether the SUAO test can track ACLR progression through rehabilitation with a larger population size, whether the test reports similar symmetry measures as the current maximal effort tests such as the single-leg hop at the 4-month mark post-surgery and whether the SUAO test can measure postural sway in ACLR patients.
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Appendix A: Letter of Information and Ethics Consent Forms

Ethics Consent Form
Letter of Introduction

Development of Clinical Tests for the Objective Measurement of Lower Limb Function

You are being invited to participate in a research study which is being supervised by Dr. Davide Bardana and Patrick Costigan from the School of Kinesiology and Health Studies. Céline Girard (MSc Candidate, Queen’s School of Kinesiology and Health Studies) will read through this consent form with you and describe procedures in detail and answer any questions you may have. If there are some words or procedures that you do not understand, please do not hesitate to ask. This study has been reviewed for ethical compliance by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board (HSREB).

Purpose of the Study
The main objective of this research is to evaluate the usefulness of using simple measurement tools in the rehabilitation of knee ligament injury or surgery to repair injured ligaments. Our study is using an accelerometer to quantify the knee’s performance. An accelerometer is a simple device that can be attached to a person to measure their motion. Accelerometers are found in many devices these days, including smartphones. The measure will give us some information about the control you have over the knee’s function. This is of importance in both sports medicine and rehabilitative medicine.

The specific aims of the study are:

• To determine how your motion improves as you go through rehabilitation.
• To determine if your knee strength influences how fast you progress during rehabilitation.
From these measures, to develop a simple, reliable tool that can be used quickly and effectively in the clinic as an adjunct to the clinician’s current evaluation protocol to assist in evaluating your rehabilitation progress.

Risks of Participation:
To the best of our knowledge, there are no added risks to participating in this study. The largest risk would be for people who have medical contraindications, such as cardiovascular problems, or musculoskeletal injuries. To accommodate these risks, you will be asked to fill out the Physical Activity Readiness Questionnaire Plus (PAR-Q+). Answering yes to any of the questions will exclude you from testing unless you are cleared by your doctor to perform any of the listed activities. Another possible risk is that of a pulled muscle. While this will be minimized by performing a warm-up, practice trails and by monitoring fatigue, a pulled muscle signals the end of testing for that day. A mild pulled muscle is treated with rest and if pain or stiffness continue you may want to seek medical advice. If you wish, another day will be scheduled to complete the testing.

Participant Selection
This study is open to male and female participants aged 18-80 years of age who are candidates for a single leg anterior cruciate ligament (ACL) reconstruction. You are being asked to participate in this research study either because you are currently undergoing rehabilitation after having a torn ACL surgically repaired, or you have been diagnosed with a complete or partial rupture of the anterior cruciate ligament (ACL) that will be repaired in the near future.

Study Procedures
If you decide to participate in this study, you will complete the Physical Activity Readiness Questionnaire Plus (PAR-Q+) to screen for any underlying health conditions. Additionally, you will complete the Anterior Cruciate Ligament Quality of Life questionnaire (ACL-QoL), which assesses knee function, at your physiotherapy sessions once a month. All questionnaires will be coded to ensure your privacy and, once completed, will be locked in a secure location. This questionnaire will take approximately 10 minutes to complete.

Before surgery, you will be evaluated for maximal knee extensor and flexor strength. If this was not done in the course of your preparation for surgery, it will be done in the School of Kinesiology and Health Studies’ Biomechanics and Ergonomics Lab. Before testing, you will warm-up with 3 minutes of easy stationary cycling. If you are uncomfortable or unable to perform easy cycling with your injured leg, you will perform gentle single leg hopping with your unaffected leg. As an additional warm-up, once seated
into the knee tester (dynamometer) you will be asked to bend and straighten your leg under a light (self-selected) weight, and then under a moderate (self-selected) weight. Following the warm-up, you will bend and straighten your knee with maximal effort five times. Testing will occur if you are comfortable with the testing equipment and fully understand what is being asked of you. You may decline this test or stop this test at any time without giving any reason and without any consequence to your care or involvement in the remainder of the study. This test will be done once at the start of the study and will take approximately one hour to complete.

Upon arrival at the clinic, after filling out the questionnaire(s), you will perform a general warm-up consisting of 3 minutes of cycling, walking and guided stretching exercises for the hip, knee and ankle. Following this, you will be instructed on the procedure and will perform the step-up-and-over (SUAO) test. You will stand in front of a 305mm high box. With your lead leg, you will step up onto the box. Your trail leg will rise up and over the box to step down on the other side of the box. You will then step down from the box. You will do the test at a self-selected, comfortable pace. The test will be repeated five times with each leg and the order of all 10 trials will be randomized. This procedure will be repeated at every physiotherapy clinic visit until you have been cleared to return to unrestricted physical activity by your physician. You may decline this test or stop this test at any time without giving any reason and without any consequence to your care. Stopping this test will complete your involvement with the study. This test, including the warm-up will take less than 10 minutes to complete.

**Benefits from Participation**

There are no direct personal benefits to you for participating in this study. Your participation will contribute to improvements in the design of exercise programs for rehabilitation training following a sports injury or after joint surgery. Moreover, other individuals suffering from an ACL injury may benefit from the results of this research.

**Confidentiality**

All information obtained during the course of this study is treated as strictly confidential and your identity will be protected to the fullest extent possible in all data analyses and publications. Your data will be assigned a code number and all data will be recorded and stored with that code number. In addition, the data will be encrypted and stored on computers protected by passwords known only to the principal researcher and research assistants who have been granted access. In any publication or presentation, only summary data will be used so that no individual can be identified. We wish to take some photos of one or
two study participants. These photos will include only the appendages tested to show the set-up of the equipment. If the face is in any of the photographs, it will be blurred out.

**Voluntary Participation and Withdrawal**

Your participation in this study is strictly voluntary and you will be given adequate time to decide whether you wish to participate in this study. You may decline to participate or are free to withdraw from the trial at any time without reason, without penalty or loss of benefits to which you are otherwise entitled. Your decision to decline to participate or withdraw will not affect the standard of care you receive or your relationship with your investigator(s). If you do not wish to participate or if you withdraw from this study, neither your current nor future medical care will be affected.

If you agree to participate in the trial, the investigator(s)/study coordinator(s) will ensure, with your agreement, that your family doctor is informed about your participation. The investigator(s) may also remove you from the study at any time without your consent for reasons that include: your failure to follow study requirements; the occurrence of unusual or serious side effects; anytime the investigator(s) thinks it is in your best interest; or if the study has ended. If this were to happen, you would be informed of the reason(s). You will be informed promptly of any important findings that are found from your participation.

**What does my signature mean?**

By signing below, I am indicating that:

- I have read and understood this Consent Form and I have had any questions answered to my satisfaction
- I understand my participation in the study.
- I realize that my participation is voluntary and that I can withdraw at any time without penalty.
- I was given a copy of the Information and Ethics Consent Letter to read and keep
- I realize that my personal data will be kept confidential.
- I can contact any of people in this letter if I have questions, concerns or complaints
- By signing this consent form, I do not waive my legal rights nor release the investigator(s) and sponsors from their legal and professional responsibilities.
If at any time I have further questions or concerns related to my participation in this study, I can contact:

**Patrick Costigan**, Ph.D. Associate Professor, School of Kinesiology and Health Studies, Queen’s University (613) 533-6000 x79037

**Dr. Davide Bardana**, Orthopedic Surgeon, Department of Orthopedic Surgery, Kingston General Hospital (613) 549-6666 x 6333

**Dr. John Rudan** Head of the Department of Surgery, Kingston General Hospital (613) 549-6666 x 3671

**Jean Côté**, Ph.D. Director, School of Kinesiology and Health Studies, Queen’s University (613) 533-6000 x 33054

If I have questions or concerns regarding my rights as a research participant, I can contact:

Dr. Albert Clark, Chair, Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board at 1-844-535-2988. The HSREB is a group of people who oversee the ethical conduct of research studies. These people are not part of the study team. Everything that you discuss will be kept confidential. This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, and Queen’s policies.

________________________________________________________________________

Print your Name

Date

________________________________________________________________________

Signature of Participant

________________________________________________________________________

Signature of Witness

We would like to ask at least one or two individuals to permit photos to be taken of the tasks. Please initial here if you are willing to permit photos to be taken ____________.

Witness Initials: ________________

Thank you.

Céline Girard, MSc Candidate, School of Kinesiology and Health Studies, Queen’s University

Principal Investigator
Development of Clinical Tests for the Objective Measurement of Lower Limb Function

This page is for the researchers to verify that you are willing to participate in the above study. By signing this page, you are declaring the following:

- You were given a verbal presentation about the above-mentioned research study
- You were given a copy of the Information and Ethics Consent Letter to read and keep
- You realize you can withdraw at any time without penalty or coercion
- You can contact any of people in this letter if you have questions, concerns or complaints
- You realize that your data will be kept confidential.
- By signing this consent form, you do not waive your legal rights nor release the investigator(s) and sponsors from their legal and professional responsibilities.

(Please sign and keep this page for your own records)

____________________________________  __________________
Print your Name  Date

____________________________________
Signature of Participant

____________________________________  __________________
Research Assistant  Date

If at any time I have further questions or concerns related to my participation in this study, I can contact:

**Patrick Costigan**, Ph.D. Associate Professor, School of Kinesiology and Health Studies, Queen’s University (613) 533-6000 ext: 79037

**Dr. Davide Bardana**, Orthopedic Surgeon, Department of Orthopedic Surgery, Kingston General Hospital (613) 549-6666 ext: 6333

**Dr. John Rudan** Head of the Department of Surgery, Kingston General Hospital (613) 549-6666 ext: 3671

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Ethics Consent: Researcher’s Copy

Development of Clinical Tests for the Objective Measurement of Lower Limb Function

This page is for the researchers to verify that you are willing to participate in the above study. By signing this page, you are declaring the following:

- You were given a verbal presentation about the above-mentioned research study
- You were given a copy of the Information and Ethics Consent Letter to read and keep
- You realize you can withdraw at any time without penalty or coercion
- You can contact any of the people in this letter if you have questions, concerns or complaints
- You realize that your data will be kept confidential.
- By signing this consent form, you do not waive your legal rights nor release the investigator(s) and sponsors from their legal and professional responsibilities.

(Please sign and return this page ONLY to the researchers)

______________________________________  __________________       
Print your Name                                                      Date

______________________________________
Signature of Participant                                              

______________________________________  __________________       
Research Assistant                                                    Date
QUEEN'S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS
RESEARCH ETHICS BOARD (HSREB)

HSREB Initial Ethics Clearance

April 26, 2016

Dr. Patrick Costigan
School of Kinesiology and Health Studies
Queen’s University

ROMEO/TRAQ: #6018019
Department Code: PHE-160-16
Study Title: Investigating the Progression of Knee Function during ACL Rehabilitation
Co-Investigators: Ms. C. Girard, Dr. D. Bardana
Review Type: Delegated
Date Ethics Clearance Issued: April 26, 2016
Ethics Clearance Expiry Date: April 26, 2017

Dear Dr. Costigan,

The Queen’s University Health Sciences & Affiliated Teaching Hospitals Research Ethics Board (HSREB) has reviewed the application and granted ethics clearance for the documents listed below. Ethics clearance is granted until the expiration date noted above.

- Protocol
- Anterior Cruciate Ligament Quality of Life Questionnaire
- The Physical Activity Readiness Questionnaire for Everyone
- Information/Consent Form – v2

Documents Acknowledged:

- CORE Certificates – P. Costigan and C. Girard

Amendments: No deviations from, or changes to the protocol should be initiated without prior written clearance of an appropriate amendment from the HSREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

Renewals: Prior to the expiration of your ethics clearance you will be reminded to submit your renewal report through ROMEO. Any lapses in ethical clearance will be documented on the renewal form.

Completion/Termination: The HSREB must be notified of the completion or termination of this study
through the completion of a renewal report in ROMEO.

**Reporting of Serious Adverse Events:** Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information.

**Reporting of Complaints:** Any complaints made by participants or persons acting on behalf of participants must be reported to the Research Ethics Board within 7 days of becoming aware of the complaint. **Note:** All documents supplied to participants must have the contact information for the Research Ethics Board.

Investigators please note that if your trial is registered by the sponsor, you must take responsibility to ensure that the registration information is accurate and complete.

Yours sincerely,

Albert L. Clark
Chair, Health Sciences Research Ethics Board

*The HSREB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations, Canadian General Standards Board, and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP). Federalwide Assurance Number: FWA#:00004184, IRB#:00001173*

*HSREB members involved in the research project do not participate in the review, discussion or decision.*
Appendix B: Physical Activity Readiness Questionnaire Plus (PAR-Q+)

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

SECTION 1 - GENERAL HEALTH

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.

1. Has your doctor ever said that you have a heart condition OR high blood pressure?  
   YES  NO

2. Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?  
   YES  NO

3. Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over-breathing (including during vigorous exercise).  
   YES  NO

4. Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?  
   YES  NO

5. Are you currently taking prescribed medications for a chronic medical condition?  
   YES  NO

6. Do you have a bone or joint problem that could be made worse by becoming more physically active?  
   YES  NO

7. Has your doctor ever said that you should only do medically supervised physical activity?  
   YES  NO

If you answered NO to all of the questions above, you are cleared for physical activity.

Go to Section 3 to sign the form. You do not need to complete Section 2.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow the Canadian Physical Activity Guidelines for your age (www.csep.ca/guidelines).
- You may take part in a health and fitness appraisal.
- If you have any further questions, contact a qualified exercise professional such as a CSEP Certified Exercise Physiologist® (CSEP-CEP) or CSEP Certified Personal Trainer® (CSEP-CPT).
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the questions above, please GO TO SECTION 2.

Delay becoming more active if:
- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better.
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed X for Pregnancy before becoming more physically active OR
- Your health changes – please answer the questions on Section 2 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity programme.
# Section 2 - Chronic Medical Conditions

Please read the questions below carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th>Question</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have Arthritis, Osteoporosis, or Back Problems?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b. Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondyloysis/pars defect (a crack in the bony ring on the back of the spinal column)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1c. Have you had steroid injections or taken steroid tablets regularly for more than 3 months?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you have Cancer of any kind?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a. Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b. Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you have Heart Disease or Cardiovascular Disease?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td></td>
<td></td>
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<tr>
<td>3b. Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3c. Do you have chronic heart failure?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3d. Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3e. Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?</td>
<td></td>
<td></td>
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<tr>
<td>Do you have any Metabolic Conditions?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4a. Is your blood sugar often above 13.0 mmol/L? (Answer YES if you are not sure)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4b. Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4c. Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you have any Mental Health Problems or Learning Difficulties?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This includes Alzheimer’s, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5b. Do you also have back problems affecting nerves or muscles?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Please read the questions below carefully and answer each one honestly: check YES or NO.

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>6. Do you have a Respiratory Disease?</strong>&lt;br&gt;This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?&lt;br&gt;(Answer NO if you are not currently taking medications or other treatments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6b. Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6c. If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6d. Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?</td>
<td></td>
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<tr>
<td><strong>7. Do you have a Spinal Cord Injury? This includes Tetraplegia and Paraplegia</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?&lt;br&gt;(Answer NO if you are not currently taking medications or other treatments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7b. Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7c. Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>8. Have you had a Stroke?</strong>&lt;br&gt;This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8a. Do you have difficulty controlling your condition with medications or other physician-prescribed therapies?&lt;br&gt;(Answer NO if you are not currently taking medications or other treatments)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8b. Do you have any impairment in walking or mobility?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8c. Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>9. Do you have any other medical condition not listed above or do you live with two chronic conditions?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9a. Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9b. Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9c. Do you currently live with two chronic conditions?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please proceed to Page 4 for recommendations for your current medical condition and sign this document.
PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active:

- It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP or CSEP-CPT) to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually – 20-60 min. of low- to moderate-intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate-intensity physical activity per week.
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the follow-up questions about your medical condition:

- You should seek further information from a licensed health care professional before becoming more physically active or engaging in a fitness appraisal and/or visit a qualified exercise professional (CSEP-CEP) for further information.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better.
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes - please talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity program.

SECTION 3 - DECLARATION

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The Canadian Society for Exercise Physiology, the PAR-Q+ Collaboration, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.
- Please read and sign the declaration below:

  I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a trustee (such as my employer, community/fitness centre, health care provider, or other designated) may retain a copy of this form for their records. In these instances, the trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME: ___________________________ DATE: ___________________________

SIGNATURE: ___________________ WITNESS: _______________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _______________________

For more information, please contact:
Canadian Society for Exercise Physiology
www.csep.ca

KEY REFERENCES

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

CSEP approved Sept 12 2011 version
Appendix C: Mohtadi’s Anterior Cruciate Ligament Quality of Life (ACL-QoL) Questionnaire

DIRECTIONS: Please answer each question with respect to the current status, function, circumstances and beliefs surrounding your anterior cruciate (ACL) deficient knee. Consider the last three months.

Indicate with a slash (/) on the line, the point ranging from 0 to 100 which most closely represents your situation.

For example, the following question:

Is this a good questionnaire?

0  __________________________________________ 100

Useless    Fantastic

If the slash is placed in the middle of the line, this indicates that the questionnaire is of average quality, or in other words, between the extremes of ‘useless’ and ‘fantastic’. It is important to put your slash at either end of the line if the extreme descriptions accurately reflect your situation.
Section A:

The first four questions are related to: SYMPTOMS & PHYSICAL COMPLAINTS.

1. With respect to your overall knee function. How troubled are you, by “giving way” episodes? (Make a slash at the extreme right if you are experiencing no giving way episodes in your knee. Please note that this question has two parts. It is concerned with both, the severity (1a) and frequency (1b) of the giving way episodes).

   1a  0 ________________________________ 100

   Major giving way episodes  Minor giving way episodes

   0 ________________________________ 100

   Constantly giving way  Never giving way

2. With any kind of prolonged activity (i.e. greater than half an hour) how much pain or discomfort do you get in your knee?

   0 ________________________________ 100

   Severe pain  No pain at all

3. With respect to your overall knee function, how much are you troubled by stiffness, or loss of motion in your knee

   0 ________________________________ 100

   Severely troubled  Not troubled at all
4. Consider the overall function of your knee and how it related to the strength of your muscles: How weak is your knee?

0 ___________________________ 100

Extremely weak  Not weak at all

Section B: The following questions are being asked with respect to your job or vocation (i.e. WORK RELATED CONCERNS). The questions are concerned with your ability to function at work and how your knee has affected your current work-related concerns. If you are a full-time student/home maker, then consider this and any part-time work together. Consider the last three months.

*** If you are CURRENTLY NOT EMPLOYED for reasons OTHER THAN YOUR KNEE then place a check on this line. _________

5. How much trouble do you have, because of your knee with turning or pivoting motions at work? (Make a slash at the extreme left if you are unable to work because of the knee.)

0 ___________________________ 100

Severely troubled  No trouble at all

6. How much trouble do you have, because of your knee, with squatting motions at work? (Make a slash at the extreme left if you are unable to work because of the knee.)

0 ___________________________ 100

Severely troubled  No trouble at all
7. How much of a concern is it for you to miss days from work, due to problems or re-injury to your knee? (Make a slash at the extreme left if you are unable to work because of the knee.)

0 ___________________________________________ 100

An extremely significant concern       No concern at all

8. How much of a concern is it for you to lose time from “school” or work because of the treatment of your ACL deficient knee?

0 ___________________________________________ 100

An extremely significant concern       No concern at all

Section C: The following questions are being asked with respect to your RECREATIONAL ACTIVITIES, SPORT PARTICIPATION OR COMPETITION. The questions are concerned with your ability to function and participate in these activities as they relate to your anterior cruciate ligament (ACL) deficient knee. Consider the last three months.

9. How much limitation do you have with sudden twisting and pivoting movements or changes in direction?

0 ___________________________________________ 100

Totally limited       No limits

10. How much of a concern is it for you that your sporting/recreational activities may result in the status of your knee to worsen?

0 ___________________________________________ 100

An extremely significant concern       No concern at all
11. How does your current level of athletic or recreational performance, 
   compare to your pre-injury level?

0  ____________________________________________________________________________  100
   Totally limited

   No limitations

12. With respect to the activities or sports that you currently desire to be 
   involved with, how much have your expectations changed because of the 
   status of your knee?

0  ____________________________________________________________________________  100
   Expectations totally lowered

   Expectations not lowered at all

13. Do you have to play your recreation/sport under caution?  (Make a slash at 
   the extreme left if you are unable to play recreation/sport because of your knee)

0  ____________________________________________________________________________  100
   Always play under caution

   Never play under caution

14. How fearful are you of your knee “giving way” when playing recreation/
   sport?  (Make a slash at the extreme left if you are unable to play recreation/ sport 
   because of your knee)

0  ____________________________________________________________________________  100
   Extremely fearful

   No fear at all

15. Are you concerned about environmental conditions, such as a wet playing 
   field, a hard court, or the type of gym floor when involved in your recreation/
   sport?  (Make a slash at the extreme left if you are unable to play recreation/ sport 
   because of your knee)

0  ____________________________________________________________________________  100
16. Do you find it frustrating to have to consider your knee with respect to your recreation/sport?

0 0

17. How difficult is it for you to “go full out” at your recreation/sport? (Make a slash at the extreme left if you are unable to play recreation/sport because of your knee)

0 0

18. Are you fearful of playing contact sports? (Circle to “N/A” at the right of the scale if you do not play contact sport for reasons other than your knee)

0 N/A

The following questions are specifically asking about two most important sports or recreational activities that you do or that you wish to do. Please write them in order of importance.

1. ____________________________

2. ____________________________
19. How limited are you in playing the number “1” sport/recreational activity?
(Make a slash at the extreme left if you are unable to play recreation/sport because of your knee)

0................................................................................................................. 100

Extremely limited........................................................................... Not limited at all

20. How limited are you in playing the number “2” sport/recreational activity?
(Make a slash at the extreme left if you are unable to play recreation/sport because of your knee)

0................................................................................................................. 100

Extremely limited........................................................................... Not limited at all

Section D: The following questions are being asked with respect to your LIFESTYLE. The questions are concerned with your lifestyle in general and should be considered outside of your work and recreation/sport activities as they relate to your anterior cruciate ligament (ACL) deficient knee.

21. Do you have to concern yourself with general safety issues (e.g. carrying small children, working in the yard, etc.) with respect to your ACL deficient knee?

0................................................................................................................. 100

Extremely concerned......................................................................... No concern at all

22. How much has your ability to exercise and maintain fitness been limited by your knee problem?

0................................................................................................................. 100

Totally limited........................................................................... Not limited at all
23. How much has your enjoyment of life been limited by your knee problem?

0  ___________________________________________________________________________  100
Totally limited  No limited at all

24. How often are you aware of your knee problem?

0  ___________________________________________________________________________  100
All of the time  None of the time

25. Are you concerned about your knee, with respect to lifestyle activities that you and your family do together?

0  ___________________________________________________________________________  100
Extremely concerned  No concern at all

26. Have you modified your lifestyle to avoid potentially damaging activities to your knee?

0  ___________________________________________________________________________  100
Totally modified  No modifications

Section E: The following questions are being asked regarding your SOCIAL AND EMOTIONAL concerns with respect to your knee. The questions are about your attitudes and feeling as they relate to your anterior cruciate deficient knee.
27. Does it concern you that your competitive needs are no longer being met because of your knee problem? (Make a slash at the extreme right if your competitive needs are being met. Make a slash at the extreme left if you do not have any competitive needs.)

0   100

Extremely concerned   Not concerned at all

28. Have you had difficulty being able to psychologically “come to grips” with your knee problem?

0   100

Extremely difficult   Not difficult at all

29. How often are you apprehensive about your knee?

0   100

All of the time   None of the time

30. How much are you troubled with lack of confidence in your knee?

0   100

Severely troubled   No trouble at all

31. How fearful are you of re-injuring your knee?

0   100

Extremely fearful   No fear at all

Thank you for completing this questionnaire.
Appendix D: SUAO and pain scores

Table D-1. Lift Acceleration, Impact Acceleration, and pain scores for each participant on each testing day.

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Note: to calculate the lift and impact symmetries, divide the affected leg over the unaffected leg’s score.
## Appendix E: ACL-QoL and TSK-11 scores

Table E-2. ACL-QoL and TSK-11 scores for each participant through rehabilitation.

<table>
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<tr>
<th>Participants</th>
<th>Days from surgery</th>
<th>ACL-QoL score</th>
<th>TSK-11 score</th>
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<td>173</td>
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Appendix F: Graphs for SUAO and questionnaires scores and lines of progression

Figure F-1. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S01 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-2. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S02 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-3. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S03 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-4. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S04 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-5. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S05 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-6. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S06 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-7. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S07 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4; 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-8. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S08 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-9. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S09 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-10. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S10 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-11. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S11 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
Figure F-12. Lift Symmetry, Impact Symmetry, ACL-QoL, TSK-11 and pain scores and lines of progression for participant S13 according to days from surgery. The Pain Visual Analog Scale scores were scaled from 100 to 10 and a score of 0 indicates no pain. The TSK-11 scores were scaled by dividing each score by 10 to give a range from 1.1-4.4 with 1.1 indicating no fear and 4.4 indicating a strong fear of re-injuring their knee. For the lift and impact symmetries, a score of 1.0 indicates perfect symmetry and scores deviating from 1.0 are increasingly asymmetrical.
### Appendix G: Shortened version of the TSK-11

#### Table G-3. A shortened version of the Tampa Scale for Kinesiophobia (TSK-11)

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<tr>
<th></th>
<th>Strongly Disagree</th>
<th>Somewhat Disagree</th>
<th>Somewhat Agree</th>
<th>Strongly Agree</th>
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<tr>
<td>1. I’m afraid I might injure myself if I exercise</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2. If I were to try to overcome it, my pain would increase</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3. My body is telling me I have something dangerously wrong</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4. People aren’t taking my medical condition serious enough.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5. My accident/problem has put my body at risk for the rest of my life</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>6. Pain always means I have injured my body</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>7. Simply being careful that I do not make any unnecessary movements is the safest thing I can do to prevent my pain from worsening.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>8. I wouldn't have this much pain if there wasn’t something potentially dangerous going on in my body</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>9. Pain lets me know when to stop exercising so that I don’t injure myself</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>10. I can’t do all the things normal people do because it’s too easy for me to get injured</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>11. No one should have to exercise when he/she is in pain.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
Appendix H: Pain Visual Analog Scale

No pain

Worst possible pain
Appendix I: Regression Models

Table H-4. Regression Models for all participants for the lift acceleration, impact acceleration, pain scores and fear of re-injury scores.

<table>
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<th>Participants</th>
<th>Lift Acceleration</th>
<th>Impact Acceleration</th>
<th>Pain</th>
<th>Fear of re-injury</th>
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<tr>
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</table>

a = slope; b = intercept for the linear regression for Lift Symmetry, Impact Symmetry, and Fear of re-injury (equation is \( y = ax + b \))
c = multiplier; d = slope for the power regression for Pain scores (equation is \( y = cx^d \))