PHYSICAL ACTIVITY AND OTHER HEALTH-RELATED OUTCOMES AFTER KNEE INJURY IN YOUTH AND YOUNG ADULTS

by

Allison Mairi Ezzat

B.A., Queen's University, 2004

B.Sc.PT, Queen's University, 2005

M.Cl.Sc., Western University, 2009

M.Sc., University of British Columbia, 2012

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPY

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Population and Public Health)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

June 2019

The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the dissertation entitled:

PHYSICAL ACTIVITY AND OTHER HEALTH-RELATED OUTCOMES AFTER KNEE INJURY IN YOUTH AND YOUNG ADULTS

submitted by Allison Mairi Ezzat in partial fulfillment of the requirements for

the degree of Doctor of Philosophy

in Population and Public Health

Examining Committee:

Mariana Brussoni
Co-supervisor

Carolyn Emery
Co-supervisor

Louise Mâsse
Supervisory Committee Member

Teresa Lui-Ambrose
University Examiner

Mark Beauchamp
University Examiner

Abstract

Traumatic knee injuries are among the most common sport-related injuries sustained by youth and are associated with significant personal and societal burden, including increased risk of post-traumatic osteoarthritis (PTOA). Despite the key role of physical activity (PA) in prevention of disease, disability, and death, there is a paucity of knowledge surrounding PA participation, and other health-related outcomes for these individuals. The overarching aim of this dissertation was to understand the attitudes and beliefs, health-related outcomes, and PA participation of youth and young adults after recovery from acute knee injury, yet before onset of symptomatic joint disease.

This dissertation is comprised of four studies. First, qualitative interviews were conducted with youth and young adults 3-10 years following intra-articular knee injury examining the influence of their injury on attitudes and beliefs about PA and PTOA. Four main themes were: acceptance of the injury impact; high determination and resiliency; lack of knee confidence; and evolving sense of athletic identity.

Second, knee confidence was quantitatively examined in youth and young adults 3-10 years after intra-articular knee injury and age-and sport-matched uninjured controls. Individuals with a previous knee injury had over seven times greater odds of being troubled by knee confidence than controls.

Third, the Swedish Knee Self-Efficacy scale (K-SES) was translated and cross-culturally adapted into English for individuals with an intra-articular knee injury in the previous five years.

Measurement properties were evaluated and revealed high internal consistency, acceptable validity, and very good reliability.

Fourth, objectively measured PA and other health-related outcomes were examined in female youth and young adults, 1-2 years after anterior cruciate ligament reconstruction (ACLR), as well as in age-and-sport-matched uninjured female controls. Participants with previous ACLR had less vigorous PA; increased knee pain and symptoms; reduced function in sports; lower quality of life; as well as poorer neuromuscular control than controls.

Taken together, these studies highlight specific longer-term physical and psychological health-related outcomes that should be addressed in youth and young adults with previous knee injury. They support that these individuals deserve intervention beyond the traditional injury recovery period with the ultimate goal of preventing PTOA.

Lay Summary

Knee injuries are common in youth sport. However, injuries can have negative consequences, including future joint problems, like osteoarthritis. Little is known about physical activity and other aspects of health in youth and young adults who have had previous knee injuries. This thesis aims to understand health outcomes, like physical activity, in these individuals. One study explores the attitudes and beliefs of young adults with previous knee injury and found they accepted its impact on physical activity. The second study found many young adults with previous knee injury were troubled by lack of knee confidence. Another study translated and adapted a scale measuring knee self-efficacy into English. The last study found that females with previous knee injury had less vigorous physical activity and poorer health outcomes than uninjured girls. This thesis shows youth and young adults have health issues in the years after knee injury that must be addressed.

Preface

Chapter 1. I wrote this chapter with intellectual input from Carolyn Emery, Mariana Brussoni, and Louise Mâsse.

Chapter 2. A version of this material has been published as Ezzat AM, Brussoni, M, Whittaker JL, Emery CA. A qualitative investigation of the attitudes and beliefs about physical activity and post-traumatic osteoarthritis in young adults 3-10 years after intra-articular knee injury. Phys Ther Sport 2018;32:98-108. This project took place at the University of Calgary and was part of phase one of the longitudinal historical cohort "The Alberta Youth Prevention of Early OA Study" (PrE-OA). I developed the qualitative study design and methodology with intellectual input from Carolyn Emery, Mariana Brussoni, and Jackie Whittaker. Ethical approval for this study was provided by the Conjoint Health Research Ethics Board at the University of Calgary (ID# 25075) and the Children's and Women's Health Centre of British Columbia Behavioural Research Ethics Board (H13-00720). I conducted all qualitative interviews and transcribed two interviews myself, while a transcriptionist (Sue Parker) transcribed remaining interviews. I independently coded all interviews and developed the analytic framework. Based on this framework, team members (Katie Wadden and Genevieve Creighton) coded one of every four interviews. I led reflective discussions of emerging themes to solidify interpretations of data with these collaborators. I was responsible for final interpretation of results and wrote the manuscript with intellectual input from all co-authors.

Chapter 3. A version of this material has been published as Ezzat AM, Whittaker JL, Toomey C, Doyle-Baker PK, Brussoni M, Emery CA. Knee confidence in youth and young adults at risk of

post-traumatic osteoarthritis 3-10 years following intra-articular knee injury. J Sci Med Sport 2018;27(7):671-675. This project was part of phase one of the longitudinal historical cohort "The Alberta Youth Prevention of Early OA Study" (PrE-OA) managed by Carolyn Emery. Ethical approval for this study was provided by the Conjoint Health Research Ethics Board at the University of Calgary (ID# 25075) and the Children's and Women's Health Centre of British Columbia Behavioural Research Ethics Board (H13-00720). I contributed to the development of the study design and participated in data collection with the research team at the Sport Injury Prevention Research Centre (SIPRC) at University of Calgary. I conducted statistical analysis, interpreted resulted, and wrote the manuscript with intellectual input from all coauthors.

Chapter 4. I designed the study in collaboration with Louise Mâsse with intellectual input from Jackie Whittaker, Mariana Brussoni, and Carolyn Emery. Ethical approval was obtained from University of British Columbia Children's and Women's Research Ethics Board (H16-01183) and University of Alberta Research Ethics Board (Pro00066873). I oversaw the translation and cross-cultural adaptation of the scale, which included collaborations with translators and a multi-disciplinary expert committee. I conducted and analyzed all pre-testing cognitive interviews. I coordinated the main study recruitment procedures across three sites and screened all participants by phone or email for inclusion. Amy Schneeberg and Jeffrey Bone provided statistical support. I conducted statistical analysis, interpreted results, and wrote the manuscript with intellectual input from Louise Mâsse, Jackie Whittaker, Mariana Brussoni, and Carolyn Emery.

Chapter 5. I developed the study design and methodology with intellectual input from Carolyn Emery, Mariana Brussoni, and Louise Mâsse. Ethical approval for this study was obtained from

University of British Columbia Behavioural Research Ethics Board (H16-01938). I performed all data collection procedures. Kathryn Soo and Larissa Taddei assisted with data cleaning. Amy Schneeberg, Alex Zheng, and Luz Maria Palacios-Derfingher provided statistical support. I conducted statistical analysis, interpreted resulted, and wrote the manuscript with intellectual input from Carolyn Emery, Mariana Brussoni, and Louise Mâsse.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ACL	anterior cruciate ligament
ACLR	anterior cruciate ligament reconstruction
ACL-RSI	Anterior cruciate ligament-return to sport after injury scale
AE	athlete exposures
AIMS	Athletic identity measurement scale
BC	British Columbia
BMI	body mass index
CFA	confirmatory factor analysis
CI	confidence interval
CM	centimetres
COSMIN	COnsensus-based Standards for the selection of health Measurement INstruments
CHMS	Canadian Health Measures Survey
CSEP	Canadian Society for Exercise Physiology
DXA	duel energy x-ray absorptiometry
EQ-5D	EuroQOL (quality of life), 5 dimensional
EULAR	European League Against Rheumatism
FMI	fat mass index
GLTQ	Godin-Shepard Leisure Time Questionnaire
ICC	intraclass correlation coefficient
IQR	interquartile range
KG	kiliogram

K-SES	Knee self-efficacy scale
$K\text{-}SES_{present}$	Knee self-efficacy scale, present sub-scale
$K\text{-}SES_{future}$	Knee self-efficacy scale, future sub-scale
KOOS	Knee injury and osteoarthritis outcome score
LOA	limits of agreement
LOE	line of equity
MCID	minimal clinically important difference
MD	mean difference
MHLC	Multi-dimensional health locus of control scale
MOA	medical office assistant
MOAKS	MRI knee OA score
MRI	magnetic resonance imaging
MVPA	moderate and vigorous physical activity
OA	osteoarthritis
OLR	One leg rise
OR	odds ratio
PA	physical activity
PAG	physical activity guidelines
PAR-Q	Physical activity readiness questionnaire
PrE-OA	The Alberta Youth Prevention of Early OA Study
PRO	patient reported outcomes
PROM	patient reported outcome measures
PTOA	post-traumatic osteoarthritis

REDCap	Research electronic data capture
RMSEA	Root Mean Square Error of Approximation
RR	relative risk
RTS	return to sports
SCT	social cognitive theory
SD	standard deviation
SDC	smallest detectable change
SDC_{ind}	smallest detectable change between individuals
SDC_{group}	smallest detectable change between groups
SEM	standard error of measurement
SIPRC	Sport Injury Prevention Research Centre
TAS	Tegner activity level scale
TJR	total joint replacement
TSK-11	Tampa scale of kinesophobia (short form)
TSI	time since injury
TSLH	triple single leg hop
TWT	total wear time
UBC	University of British Columbia
US	United States
YLD	years lived with disability

Acknowledgements

This dissertation would not have been possible without the generous contributions of many individuals and organizations. Professor Carolyn Emery, thank you for seeing potential in my research abilities and for having the flexibility to supervise me across provinces. Your academic rigor, passion for research, and drive to succeed are inspiring. Professor Mariana Brussoni, thank you for welcoming me to your lab, providing unwavering support, and insightful contributions to this work, despite its differences from your own research priorities. Professor Louise Mâsse, thank you for sharing your expertise and providing honest feedback that has truly enhanced the quality of this dissertation. To the three of you, thank you for your time in forming my Committee and for fostering a supportive and encouraging learning environment, while also challenging me to think outside of my comfort zone throughout this process.

Beyond my Committee, there are numerous mentors, clinicians, colleagues, and friends without whom I would not have succeeded. Thank you, Jackie Whittaker, for your guidance navigating this journey, your availability for listening, and your ability to provide constructive feedback. Thank you, Alison Hoens, for offering an open door and encouraging me to find my own path. Thank you, Amy Schneeberg, for sharing the highs and lows of doctoral training and being willing to 'talk stats' at all hours. Thank you, Karim Khan, Robin Roots, Nicola Jones, and Ewa Roos, for each inspiring me with your own passions for learning, teaching, and research, as well as your immense generosity of time.

To the entire team at the SIPRC in Calgary, thank you for making me feel a part of a greater goal and for providing encouragement, friendship and a 'home away from home.' Thank you, Rick

Celebrini, Damien Moroney, and all the physiotherapists and staff at Fortius Sport and Health for your kindness in welcoming me into your space and openness to engage in the research process. Thank you, Ian Pike, Kishore Mulpuri, Dawn Mount, and everyone at Evidence to Innovation Research theme at BC Children's Hospital Research for your support and encouragement.

I am grateful for the financial support that made this dissertation possible. Thank you to the Canadian Child Health Clinician Scientist Program, for the funding that allowed me to focus on my doctoral research full time, as well as providing unique learning opportunities abroad. Thank you to BC Children's Hospital Research Institute, for the financial support for both myself and my projects, as well as numerous opportunities that have greatly enhanced my research training experience. Thank you, to the Physiotherapy Association of British Columbia for your generosity in funding various research travel endeavors. Thank you, to Alberta Team Osteoarthritis and School of Population and Public Health, University of British Columbia for the additional support.

Lin and Ahmed Ezzat, thank you for your infinite support and help that has contributed to my success in this endeavor. Mary Anne and John Mackay, Mom and Dad, thank you for instilling a love of learning in me at a young age and for your unfailing support and love. After five University degrees, I promise to graduate for good one day. Ramsey, thank you for having the confidence in me to pursue my passions. It would not have been possible without your endless patience and immeasurable support. You gracefully moderated my emotional ups and downs and kept me focused on what was important day to day so I could see this project to fruition.

Sienna and Aiden, while I set out to create new knowledge, you are the most important products of the past 6 years. Thank you for reminding me what truly matters.

To my parents, Mary Anne and John Mackay, who have always believed in me and provided endless encouragement to pursue my dreams.

Chapter 1: **Introduction**

Knee injuries sustained by youth and young adults are a serious public health concern given their rising frequency and role as potential catalysts for negative long-term health implications, such as reduced quality of life and early degenerative joint changes.[1–3] Post-traumatic osteoarthritis (PTOA) is a unique subtype of osteoarthritis (OA) affecting younger individuals with a history of articular injury.[1,3] It can lead to disability that impedes participation in physical activity (PA) including sports, daily activities, and occupational tasks.[4] Given the role of PA in prevention of chronic disease, disability, and death worldwide,[5–7] the implications for disrupted participation at a young age represent a grave health risk.

Numerous evidence-based clinical guidelines have been developed for the rehabilitation of serious knee injuries,[8,9] as well as for the management of knee OA.[10–12] However, much less is understood about the time period after recovery from acute knee injury, yet before the clinical diagnosis of PTOA, approximately 10-15 years later in about 50% of individuals who have had an intra-articular knee injury. This time frame represents a unique opportunity for secondary prevention strategies that could delay or prevent the onset of joint disease.

PA has been touted as essential for physical, psychological, social, and cognitive health across the lifespan.[13] PA benefits all body systems including the cardiovascular system, brain performance, as well as bone and joint health.[6,14,15] However, the vast majority of research examining PA outcomes after knee injury in adolescents has focused narrowly

on return to sport (RTS) failing to examine the broader aspects of PA in this population. While making a return to the same level of competitive sport is often seen as a key goal of rehabilitation,[16] it may not be the most appropriate indication of successful recovery or long-term joint health.

Youth and young adults must be a research priority for understanding health outcomes after knee injury given the serious lifelong ramifications of such injuries. PA participation after knee injury is unknown, representing a significant knowledge gap given the importance of exercise for joint health.[17,18] In particular, specific insight on PA in female youth and young adults after knee injury is warranted due to females' overall lower level of PA participation,[19] higher knee injury rate,[20] lower RTS rate after knee injury,[21] and higher prevalence of knee OA compared to their male counterparts.[22]

The overarching aim of this dissertation was to develop an understanding of the attitudes and beliefs about PA, selected physical and psychological health-related outcomes, and PA participation of youth and young adults after recovery from acute knee injury, yet before the onset of symptomatic joint disease. This period is thought to be a critical phase where secondary prevention strategies for PTOA, such as a neuromuscular training intervention, could be implemented. Chapter 1 provides an overview of the epidemiology and burden of knee injuries in youth and young adults and highlights the sex disparity seen in knee injury rates. Next, the rehabilitation of knee injuries is discussed, along with the role of patient reported outcome measures and key health-related outcomes after knee injury including recurrent injury, body composition, RTS, and PTOA. PA participation is

summarized across three groups: youth and young adults; individuals who have had a previous injury; and individuals with knee OA. Lastly, a critical appraisal examines the current state of the evidence underpinning the impetus for this thesis. Ultimately, this chapter summarizes the evidence in the field, highlights key knowledge gaps, and provides the rationale for the research that comprises this dissertation.

1.1 Knee injury epidemiology

Sustaining an acute knee injury, including damage to structures such as ligaments, menisci, cartilage, and bone, is among the most common injuries in physically active youth and adults.[23] A ten year study documenting over 19,000 athletic injuries, found 39.8% of all injuries involved the knee joint.[23] Knee injuries most often occur during sports that involve jumping, cutting, or pivoting motions.[24] Soccer, a sport boasting one of the highest sport participation levels worldwide,[25] is associated with a high occurrence of knee injuries.[26,27] Surveillance data of soccer-related knee injuries that required medical attention from the National Collegiate Athletic Association (2004-2009) reported a knee injury rate of 1.06 injuries per 1000 athlete exposures.[28] Knee injuries can be more severe than injuries to other body parts and result in lengthy rehabilitation, frequently accompanied by surgery.[2] This high injury incidence may be due to the anatomical and biomechanical complexity of the knee, along with its necessity to sustain large weight bearing forces, and provide stability during multi-directional movement.[2]

Among knee traumas, anterior cruciate ligament (ACL) rupture is one of the most devastating acute injuries for active individuals. The ACL plays a crucial role in anterior-

posterior translational and internal-external rotational stability of the tibio-femoral joint.[29] Swedish data suggest an incidence rate of 80 injuries per 100,000 person-years in that country, resulting in 6,000 ACL ruptures per year.[30] If translated to North America, this estimates 250,000 and 30,000 ACL ruptures per year in the United States (US) and Canada, respectively. These numbers reaffirm estimates of ACL reconstruction (ACLR) in the US, [80,000-250,000 annually][31,32] where surgery is the accepted standard of care.[31] Notably, these authors also concur that rates of ACL rupture and surgery are rising most rapidly in females and individuals younger than 20 years of age.[30–32] Up to 50% of the time, it is estimated that ACL ruptures are accompanied by further internal damage to menisci, other ligaments, cartilage, and sub-chondral bone.[4] These concomitant injuries impact the initial treatment approach and recovery, as well as the severity of long-term consequences.[4]

Traumatic meniscus injuries can also occur independently during sport with an estimated incidence of 61 injuries per 100,000 person/year.[33] The menisci cover the superior aspect of the tibia and distribute load during weight bearing, provide necessary shock absorption, facilitate joint gliding, and act as secondary joint stabilizers.[34] Likely because of these essential functions, damage to this fibrocartilage wedge, has been increasingly linked to the development of degenerative changes.[4] Underneath the meniscus, damage can also occur to articular cartilage, a specialized type of hyaline cartilage that covers the surfaces of the bone. Articular cartilage serves as a low friction gliding surface, provides increased compressive strength to minimize peak pressure on subchondral bone, and is wear resistant in normal circumstances.[35] However, it is also aneural and avascular, thus

its ability for intrinsic reparability after injury is low.[35] Although more difficult to ascertain precise estimates, knee arthroscopies show that up to 60% of middle age individuals have signs of articular cartilage damage.[36] Traumatic sub-chondral bone lesions and contusions to the lateral femoral condyle or lateral tibial plateau region also occur alongside ACL ruptures.[37] Given these lesions can only be visualized using magnetic resonance imaging (MRI), precise incidence estimates are not available, yet there is growing interest in their role in knee pathologies.

Patella dislocation, more common in youth than adults, has an injury rate of 43 per 100,000,[38] with females a roughly 33% higher incidence than males.[39] It can be associated with ongoing morbidity including recurrent instability, articular cartilage lesions, and patellofemoral OA.[40]

Across these three primary knee injuries (ACL rupture, meniscus tear, and patella dislocation), it could be argued that injury to the ACL has the highest overall burden. This is due to ACL rupture's relatively high incidence amongst youth and young adults; the demanding and lengthy recovery period after injury and/or surgery; its high association with both recurrent injury and other knee pathology; as well as its contribution to future PTOA.

1.1.1 Knee injuries in youth

Youth knee injuries are on the rise.[26,32] This is likely due to numerous factors including increased sport participation, improved injury recognition, and the trend of young athletes

specializing and training at high intensity in a single sport at an earlier age.[26,41] The global prevalence of youth knee injuries ranges between 10% and 25%, with more recent studies reporting higher percentages.[2] Surveillance data from high schools in the US examined knee injuries by athlete exposures (AE), which they defined as one athlete participating in one practice or competition.[42] They reported an overall rate of 2.98 knee injuries per 10,000 AE, with football (6.29 per 10,000 AE) followed by girls soccer (4.53 per 10,000 AE) and girls gymnastics (4.23 per 10,000 AE) having the highest knee injury rates.[42] In sports played by boys and girls, overall girls had more knee injuries than boys [relative risk (RR)=1.52; 95% confidence interval (CI)=1.39-1.65]; and girls were more likely to sustain an ACL rupture than boys (RR=2.38; 95% CI=1.91-2.95).[42] In Canadian youth, sport account for up to 50% of all injuries,[43] with knee being one of the most frequently injured structures.[44] It is estimated that the knee and ankle represent 35-40% of youth sport-related injuries.[44] Young athletes, 15-25 years old, represent half of all those individuals who sustain an ACL rupture.[31] Female youth are a sub-group of amateur athletes that consistently have the highest incidence of ACL rupture (1 out of every 29 athletes) compared to their male counterparts (1 out of every 50 athletes).[20] Furthermore, ACL injury rates themselves are rising, especially in females.[45] For example, the incidence of ACLR in females increased significantly from 10.36 to 18.06 per 100,000 person-years between 1994 and 2006 in the United States.[32] These growing numbers of youth sport injuries may be an unfortunate precursor of rising PTOA prevalence in the following decades.

1.1.2 Knee injury risk factors

With the ultimate goal of preventing injuries in sport, numerous models have been proposed to convey the interaction of complex injury mechanisms and risk factors. The dynamic recursive model of etiology in sport injury builds on previous work by Meeuwisse [46] and Bahr[47] to emphasize the continual, cyclical adaptation that occurs during sport participation that alters both risk and etiology.[48] In this model, Meeuwisse et al. emphasis the dynamic nature of injury risk factors that are influenced, both positively and negatively, by repeated sport exposure. To prevent sport injury, one must look further than the initial set of intrinsic and extrinsic injury risk factors, to examine how these risk factors may change (adaptively or maladaptively) over time with sport participation, regardless of if they are associated with prior injury. This model illustrates the complexity and cyclical nature of changing risk factors for sport injury.

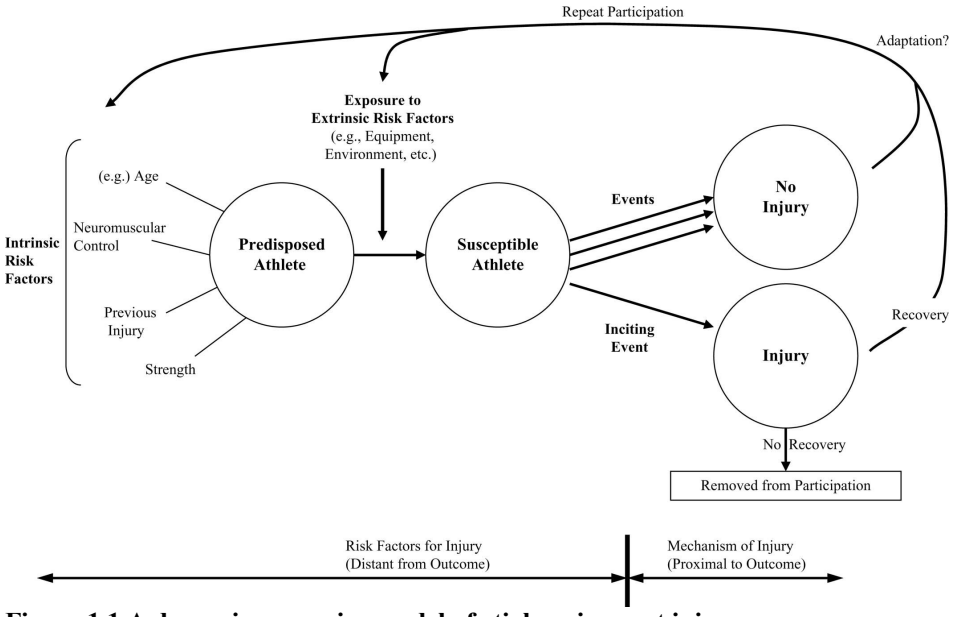


Figure 1.1 A dynamic, recursive model of etiology in sport injury

Reproduced from Clinical Journal of Sports Medicine, Volume 17, Meeuwisse, W et al. "A dynamic model of etiology in sport injury: the recursive nature of risk and causation", pp 215-19. 2007, with permission from Wolters Kluwer Health.

When applying this broad perspective that considers the multi-factorial nature of injury risk factors, the literature on knee injuries has largely focused on non-contact ACL ruptures; due to their relative frequency, homogenous nature, and shattering impact on athletes. One classification scheme uses the following four categories to group potential risk factors: environmental, anatomical, hormonal, and neuromuscular.[31] Environmental (external) risk factors include the playing surface, footwear type, meteorological conditions, and protective equipment such as knee braces. The remaining three categories involve internal factors. Anatomical risk factors include the overall alignment of the lower extremity and how this contributes to the stability of the knee (e.g. Q angle, dynamic knee valgus, and width of femoral notch.) Hormonal risk factors are sex hormones that have been shown to play a role in regulation of collagen synthesis and affect the properties of ligament loading.[49] Lastly, neuromuscular factors include altered movement patterns often visualized during jump landing or pivoting actions, altered activation patterns such as dominant quadricep contraction over hamstrings activity, and inadequate muscle stiffness leading to increased anterior tibial translation.[31] Embedded within all three internal risk factor categories, are opportunities for elevated injury risk amongst female adolescent athletes.

1.1.2.1 Sex differences in knee injuries

In two of the most common knee injuries, ACL rupture and patellar dislocations, females appear to be at significantly greater risk than their male counterparts.[20,39] Whether examined across sports or within individual sports, systematic reviews consistently report that females suffer significantly more ACL ruptures than males, with one recent meta-

analysis reporting females have 1.7 times greater incidence.[26] Experts agree it is likely the interaction of risk factors that contribute to this sex disparity.[50,51] Females have smaller ACL as assessed by cross-sectional area, length, and volume, compared to males after normalizing for body weight, as well as variations in the shape and size of the femoral notch [landmark on the distal femur from which the ACL originates.][52] Both of these anatomical differences have been hypothesized to increase ACL rupture risk in females.[50–52] While there is currently no consensus on associations between lower extremity alignment and ACL injury risk,[51] from a biomechanical perspective, males and females develop at different rates and fully mature females have greater anterior pelvic tilt, hip anteversion, tibiofemoral angle, and quadriceps angle than males.[53,54] Laxity, the presence of joint hypermobility and musculotendinous flexibility, is more prevalent in females than males[55] and this along with the higher levels of estrogen found in women during their premenstrual phases, may raise ACL rupture risk.[56] Neuromuscular factors, such as poor or asymmetrical hip control during jump landing, may increase hip adduction and knee valgus contributing to ACL rupture.[57] Further, as the tibia and femur grow during childhood and adolescence, the increased torque on the knee can cause joint instability.[58] Research suggests males may be more apt at increasing their power, strength, and coordination to compensate for growth spurts compared to females.[58,59] Thus female youth are an especially high risk group for ACL ruptures and thus should be considered a high priority for research examining short and long term injury sequelae and how best to maximize recovery.

1.2 Burden of youth knee injuries

1.2.1 Personal burden

Traumatic knee injuries can have substantial physical, psychological, and economic impacts on youth.[60] Negative short-term consequences may include increased pain, reduced physical function, and feelings of social isolation, all of which may lead to decreased present or future PA participation.[61] Data from Australia suggest 8% of youth drop out of sports annually after injury or due to fear of injury.[62] The loss of ability or motivation to engage in regular PA at a time critical to shaping lifelong healthy lifestyle behaviours is concerning, given the abundance of health benefits linked to long-term PA participation including decreased risk of chronic diseases and mortality.[6,7,63]

Despite surgical recommendations, many youth must wait for up to half a year before receiving ACLR.[31] For numerous youth, the rehabilitation process after surgery feels long and arduous, requiring support from family, friends, and rehabilitation professionals to set realistic expectations and find motivation and confidence to make a functional recovery and return to sports.[64] During this rehabilitation phase there can be substantial psychological distress,[65] in addition to time missed at school or work, as well as personal financial strain associated with physiotherapy services which can result in individuals dropping out of structured rehabilitation programs before meeting strength and functional targets to optimize recovery.[66]

1.2.2 Post-traumatic osteoarthritis

The long-term sequelae of knee injuries in youth sport can be severe including the development of PTOA,[1,3] a debilitating chronic articular disease characterized by

persistent pain, mobility disability, and reduced quality of life.[67] While OA has been traditionally characterized as a 'wear and tear' disease affecting older adults, it is now conceptualized as complete 'joint failure'.[68] Individuals with a previous knee injury have an estimated 56.8% lifetime risk of developing PTOA in that joint.[69] There have been five recent systematic reviews examining the relationship between ACL rupture with or without reconstruction and PTOA.[70–74] While each review has used different methodologies to summarize their findings, they consistently conclude there is increased prevalence and relative risk of PTOA after ACL rupture and that the risk appears to be further elevated when individuals suffer a concurrent meniscus tears.

Traditionally, PTOA was diagnosed using a combination of clinical symptoms and radiographic changes at 10-20 years subsequent to injury. This meant that youth who suffered a knee injury would be diagnosed with PTOA during middle adulthood, in the prime of their working years. Now, new imaging technologies (e.g. MRI), diagnostic frameworks [MRI OA Knee Score (MOAKS)[75]], and recognition of the importance of early treatment strategies means that individuals are being diagnosed with PTOA at an even earlier stage of young adulthood.[76] One study using MOAKS[75], diagnosed up to 1/3 of young adults (median age 26 years) with PTOA of the tibiofemoral or patellofemoral joints at one year after ACLR.[77] Another recent study examined the association between MRI-defined OA (using MOAKS) and self-reported and functional outcomes in a cohort of youth and young adults 3-10 years after a sport-related knee injury along with healthy matched controls.[78] Those in the injury group had a 10-fold (95% CI= 2.3-42.8) greater odds of MRI-defined OA compared to the control group, and having MRI-defined OA

was significantly associated with reduced quality of life.[78] This supports the high value of early identification of those with previous knee injury, if there may be an opportunity to intervene to improve quality of life.

Internationally, the Global Burden of Disease study reports that the prevalence of knee OA peaks at approximately age 50 and the largest growth since 1990 has been seen in people aged 15-49 years, especially in females.[79] Canadian studies estimate that of all newly diagnosed people with OA in Canada, half are younger than 60 years old,[80] and that by 2021 overall arthritis prevalence is predicted to increase the greatest in women aged 35-44 years.[81] Young people with PTOA represent a new public health problem given these individuals will live longer with the disease and it will most certainly influence many aspects of family life and employment.

1.2.3 Societal burden

With increasing rates of ACL rupture,[45] reconstructive surgery has become one of the most common sport medicine procedures performed in the US. Population-adjusted estimates suggest up to 250,000 ACLR performed annually.[32,82] The most current data suggests that between 1994 and 2006 the rate of ACLR performed by American surgeons increased by 37%.[82] At an estimated cost of $17,000 US per procedure, the annual financial impact of ACLR in the US is over one billion dollars, not including expenses associated with rehabilitation and other indirect costs.[24]

OA is among the leading cause of chronic pain and disability world-wide, affecting over 30 million American adults and 4.4 million Canadians.[80,83] Globally, OA is ranked 11th in years lost to disability out of 291 diseases or injuries.[22] With prevalence rates expected to markedly increase, OA is projected to be the fourth leading cause of disability by the year 2020.[84] The total financial burden of OA in the US is estimated over $100 billion annually,[85] whereas in Canada direct and indirect costs are $27.5 billion annually.[80] Examining years lived with disability (YLD), knee OA accounts for 83% of the total worldwide OA burden.[22]

PTOA represents an important and distinct sub-group of knee OA.[76] Given most of these individuals sustained a previous occupational or sport related knee injury, they typically seek medical advice at a younger age, are more active, and have overall better physical health than those who develop idiopathic OA.[241] It is likely that their expectations, lifestyle, and management of the condition will also be different. They may put higher and more frequent physical demands on their knee, thus resulting in earlier and more extensive medical care (e.g. surgical intervention) than individuals with idiopathic OA. There are an estimated 5.6 million individuals with PTOA in the United States leading to an aggregate annual economic burden of $11.8 billion, of which $3.06 billion represents direct health care expenses.[86] Further, the long term costs attributable to the future development of PTOA in these individuals is estimated at $2.78 billion/year in the US.[87] In a Canadian context, where 1 in 8 individuals have OA,[80] an estimated 1 million Canadians have PTOA. The number OA diagnoses in Canada is expected to double in the next 30 years.[80] A population-based cohort analysis from the Canadian Longitudinal

National Population Health Survey found that those with OA have 90% higher hazard of work loss due to illness or disability compared to matched non-OA individuals, after adjusting for socioeconomic, health, and work-related status.[88] These statistics emphasizes the vast and costly long-term ramifications of knee injury to Canadian society.

1.3 Rehabilitation following knee injury

The primary goal in the management of all ligament, meniscal, and cartilage knee injuries focuses on reducing symptoms and restoring physical function. Progressive exercise prescription is the hallmark treatment aiming to restore lower extremity muscle strength and neuromuscular response.[89] Neuromuscular retraining is touted to be a key aspect of rehabilitation by improving sensorimotor deficiency,[17] as well as potentially improving cartilage quality in those at high risk of PTOA.[18]

Rehabilitation programs should be intensive and individualized with the goal of helping patients recover their maximal function.[90] In North America, surgery is usually strongly recommended for young patients with more severe knee injuries, especially if their goal is to return to competitive sports.[32] Alternatively, in many European countries surgery is reserved for patients with knee instability or mechanical blockages that prevent full range of motion.[91]

Specifically with regards to ACL ruptures, reconstruction is almost always recommended for active individuals, under 40 years old.[32,92] While it is hypothesized to restore

mechanical stability of the knee and reduce the risk of subsequent meniscal tears,[93] surgery has not been proven to be protective of future PTOA.[94] Evidence suggests that prescribed exercise should start early after ACL rupture, thus beginning rehabilitation even before deciding on surgical options.[95,96] Surgery is followed by extensive rehabilitation, often with the goal of transitioning back to sport 6 to 12 months later.[97] Numerous guidelines have been published with best practice recommendations for rehabilitation after ACLR,[8,9] including an international consensus statement for the prevention, diagnosis, and treatment of pediatric ACL ruptures. [98]

1.3.1 Evaluating outcomes after knee injury

The assessment of outcomes during recovery after knee injury is essential to be able to understand the effectiveness of treatments, as well as the physical and psychological consequences of the knee injury.[99] Outcomes must be meaningful and relevant for the individual.[100] Outcomes can be broadly classified into two categories: 1) functional and structural/physiological outcomes; and 2) patient reported outcomes (PRO). More than 18 performance-based tests have been used to evaluate functional outcomes after ACL rupture,[101] with hop tests being one of the most commonly utilized.[102] Achieving a limb symmetry index (injured leg/non-injured leg) of >90% is commonly used as a criteria for initiating RTS and is associated with better long term outcomes such as reduced re-injury and better knee function.[103,104] Structural or physiological outcomes are more often used in a research setting than clinical practice and include the use of MRI and biomarkers.

PRO, described as a phenomenon or multi-dimensional construct that cannot be directly observed, are measured by instruments called patient reported outcome measures (PROM).[105] In people with a history of knee injury, PROM reveal increased knee pain and symptoms,[106] increased fear of re-injury,[107] and reduced quality of life[108] compared to pre-injury levels or population norms. It has been suggested that both functional outcomes and PRO should be used to provide complementary information to clinicians and researchers.[102]

1.3.1.1 Functional outcomes

Functional outcomes, are evaluated using performance-based measures to reflect the integration of neuromuscular control, force generating capacity, and confidence in the limb.[109] In a clinical setting, the results may guide decisions on exercise progression or RTS.[110] In research, functional outcomes may be used to gauge the effectiveness of one treatment compared to another. Given the complexity of knee function, there is no single functional outcome capable of comprehensively evaluating all aspects of knee function. Clinical practice guidelines recommend using an extensive battery of performance-based tests to evaluate an athlete after ACLR and a rehabilitation protocol that will mimic the demands of sport before they return to play.[8] The triple single leg hop (TSLH) test is one such performance-based clinical test that has been validated for use in individuals after ACL rupture[109,111] The one leg rise (OLR) test is a repeated single leg squat test which has been found to be predictive of poorer quality of life in individuals with early patellofemoral OA three years later[112] and incident radiographic knee OA in individuals five years later.[113] It has been hypothesized to be a useful performance-based test for

early identification of individuals with poor knee prognosis[113] and may be useful for evaluating younger, higher functionating patients at risk of PTOA.

1.3.1.2 Patient reported outcomes

International consensus has recommended that PROs be utilized as primary outcomes in clinical trials, as well as in clinical evaluation of knee injury outcomes.[8,114] Non-specific PROM, such as the five dimensional EuroQOL (quality of life) (EQ-5D) scale,[115] are able to evaluate broad health-related constructs across diverse patient groups or in the general population. They are useful to facilitate comparisons, although the measured constructs may not always be meaningful for a specific sub-group or be able to capture unique aspects of a condition. Therefore, validated condition-specific PROM, developed in partnership with patients and evaluated in the population of interest are essential. Commonly used knee-specific PROM include: Knee Injury and Osteoarthritis Outcome Score (KOOS)[116], Tegner Activity Level Scale (TAS),[117] ACL-Return to Sport after Injury scale (ACL-RSI),[118] Athletic Identity Measurement Scale (AIMS),[119] and Knee self-efficacy scale (K-SES).[120]

1.3.1.2.1 Measurement properties

There are numerous factors to consider when selecting the optimum PROM for use in research or clinical practice, including the construct being measured, the target population for the instrument, the associated patient burden, and the quality of the measurement properties of the PROM.[105] A measurement property is a feature of an instrument that reflects its quality.[105] With the growing number of PROM available for

use in a knee injury population, matching the ideal outcome measure for a given purpose is essential.

Historically, the framework for the evaluation of measurement properties was inconsistent and variable. COSMIN, (COnsensus-based Standards for the selection of health Measurement INstruments), was an initiative by an international multidisciplinary team of researchers aiming to improve the best-practice selection of outcome measurement instruments both in research and in clinical practice by developing a set of resources.[99] They have done considerable work on health-related outcomes measures, attempting to bring consistency, standardization, and facilitate comparison across studies. Numerous resources have been developed to help in the selection or development of a PROM including a consensus on taxonomy, terminology, and definitions;[105] a checklist for assessing methodological quality of studies on measurement properties;[121] and most recently a Risk of Bias checklist for systematic reviews of PROM.[122]

The overarching goal of COSMIN taxonomy is to promote a more uniform use of terms and definitions for further research on measurement properties.[105] Achieved via a Delphi process, the taxonomy purports three domains of measurement properties: validity, reliability, and responsiveness.[105] Validity, the extent to which a PROM successfully measures the construct(s) that it purports to measure, is divided into a number of related sub-categories, of which only some may be relevant in a given circumstance. For example, criterion validity can only be examined when a gold standard comparison exists, and cross-cultural validity is only assessed when a PROM is translated and/or

culturally adapted from its original version. Broadly, reliability, also broken down into three sub-categories, examines the stability of an instrument over repeated measures and quantifies the error associated with the instrument.[105] Lastly, responsiveness refers to the ability of an instrument to detect true change over time in the construct being measured. Interpretability is not considered a measurement property yet is included in the table as it is thought to be an important characteristic of a PROM. For complete definitions of these domains and sub-categories, see Table 1.1.

Table 1.1 Measurement properties

Reliability: The degree to which the measurement is free from measurement error		
Internal Consistency: The degree of the interrelatedness among the items[1]	**Reliability:** The proportion of the total variance in the measurements which is because of ''true'' differences among patients[1]	**Measurement Error:** The systematic and random error of a patient's score that is not attributed to true changes in the construct to be measured
Validity: The degree to which a PROM instrument measures construct(s) it purports to measure		
Content Validity: The degree to which the content of an PROM is an adequate reflection of the construct to be measured	**Construct Validity:** The degree to which the scores of an PROM are consistent with hypotheses based on the assumption that the PROM validly measures the construct to be measured	**Criterion Validity:** The degree to which the scores of an PROM are an adequate reflection of a ''gold standard''
Face Validity: The degree to which (the items of) an PROM appear to adequately reflect the construct to be measured	**Structural validity:** The degree to which the scores of an PROM are an adequate reflection of the dimensionality of the construct to be measured **Hypothesis testing:** Idem construct validity[1] **Cross-Cultural validity:** The degree to which the performance of the items on a translated or culturally adapted PROM are an adequate reflection of the performance of the items of the original version of the PROM	
Responsiveness: The ability of a PROM to detect change over time in the construct to be measured		
Interpretability:* The degree to which one can assign qualitative meaning, that is clinical or commonly understood connotations to an instrument's quantitative scores or change in scores.		

PROM: patient reported outcome measure; *Interpretability is not considered a measurement property but an important characteristic of a PROM

Adapted from Journal of Clinical Epidemiology, Volume 63, Mokkink et al. "The COSMIN study reached international consensus on taxonomy, terminology, and definitions of measurement properties for health-related patient reported outcomes", pp 737-745. 2010, with permission from Elsevier.

A contemporary conceptualization of validity is that it is a unitary concept that depends on the accrual of evidence from five different sources.[123] This perspective was developed in an attempt to reduce confusion about the different 'types' of validity (i.e. content,

criterion, and construct validity), by considering them all to be 'sources' of validity.[124] Further, validity pertains to inferences or interpretations made about a set of scores or measurements, as opposed to a property of an instrument.[125] The validity of a set of scores is based on the integration of different sources of validity evidence. Figure 1.2 shows the five sources of validity evidence and how they are related to the previously discussed types of validity.

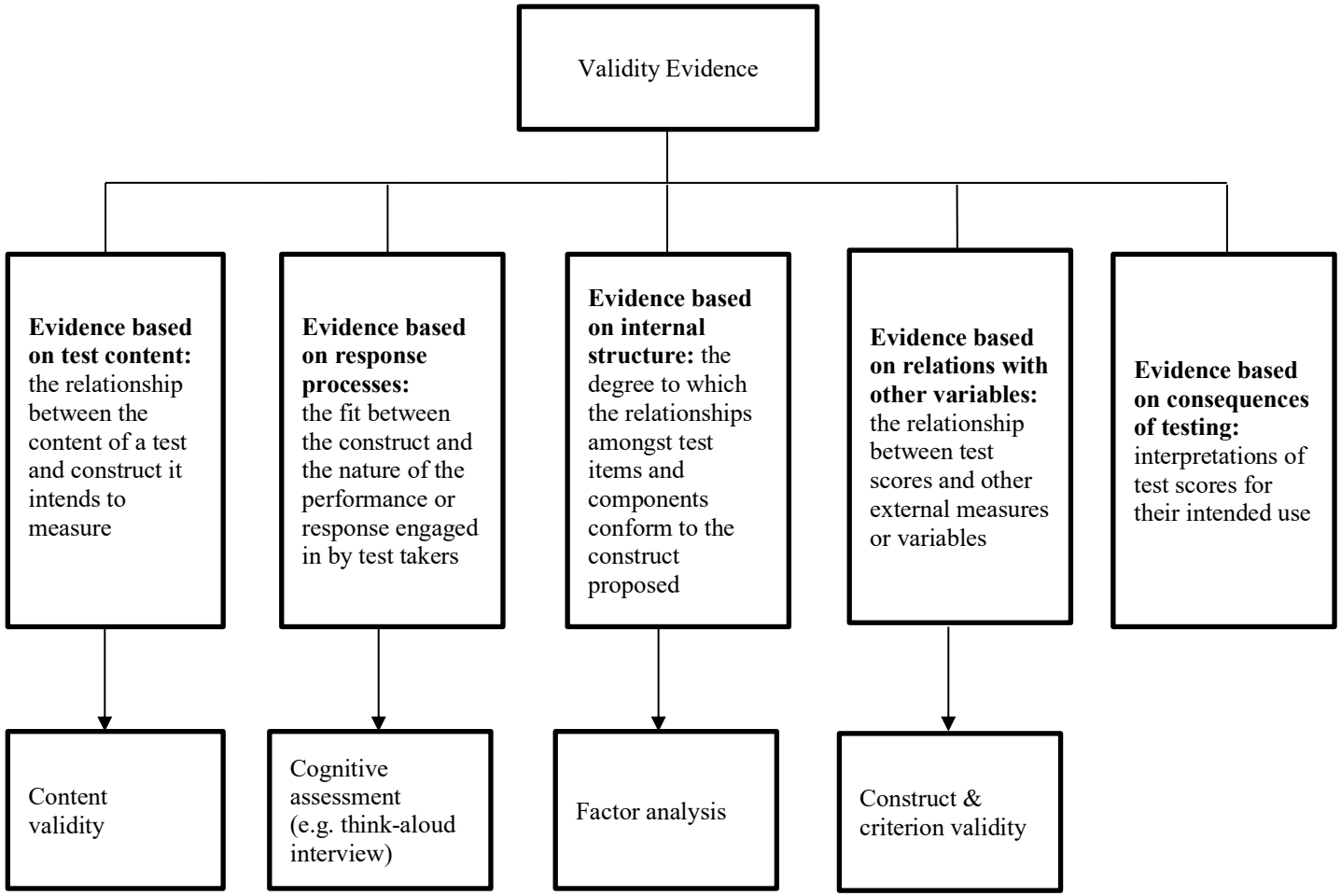


Figure 1.2 Sources of evidence to support validity of a set of scores (contemporary validity theory) and types of validity (historical approach)

Adapted American Educational Research Association, American Psychological Association, and National Council on Measurement in Education (2014) Standards for Educational and Psychological Testing, Washington, DC.

1.3.1.2.2 Cross-cultural adaptation

A cross-cultural adaptation is the multi-step process involving translation and evaluation of the measurement properties of a PROM in an alternative language or cultural setting than it was originally developed.[105] To aid in the goal of reaching equivalence between the original source and target versions of the questionnaire, a standardized protocol for a cross-cultural adaption has been developed.[126,127] It involves multiple translations, review by an expert committee, and pre-testing in a sample of the target population in order to achieve linguistic and content parity. The final step is the evaluation of the measurement properties.

1.3.1.3 Knee specific patient reported outcome measures

Twenty-four unique knee-specific PROM have been designed to measure outcomes from the perspective of the individual, although few have had their measurement properties substantially evaluated.[128] One of the most frequently used PROM for individuals with knee injury[102] is the KOOS, a comprehensive measure that has been used in individuals with previous ACL rupture (both reconstructed and conservatively managed); meniscectomy; and PTOA.[116,129] It consists of five subscales: pain, other symptoms, function in daily living, function in sport and recreation, and knee-related quality of life. Normative scores for a young, active college aged population without a history of knee injury have been published.[130] One item from the KOOS knee-related quality of life sub-scale, has been used as a stand-alone assessment of knee confidence.[131,132] Another PROM with validated scores is the ACL-RSI Scale that was developed to evaluate psychological readiness to RTS participation after ACLR in terms of emotions,

confidence in performance, and risk appraisal.[118] It consists of 12 items (e.g. how confident are you that you can perform at your previous level of sports participation) each rated from 0= 'not at all' to 10 ='extremely.' An overall mean score is reported with a higher score indicating greater psychological readiness to return to activity. It has been found to have high internal consistency (Cronbach's α =0.95) and high reproducibility (ICC=0.89).[118] It has shown the ability to discriminate between individuals who did and did not return to self-reported pre-injury PA after ACLR.[118,133] Psychological readiness measured before ACLR surgery has been associated with greater RTS participation at the 12 month mark.[134]

Developed in Sweden, the knee self-efficacy scale (K-SES)[120] is a measure designed to gauge perceived self-efficacy of knee function in two subscales: current tasks and future capabilities.[120] The validity of scores has been examined in individuals after ACL rupture. Participants respond to 22 items (0='not at all certain' to 10='very certain' about the task). The item scores for each subscale are summed and divided by the number of questions in order to obtain a final score for each sub-scale with a higher score indicating higher self-efficacy. It has been found to have good test-retest reliability (ICC=0.75) and high internal consistency (Cronbach's α =0.78-0.94).[120] Construct validity has been demonstrated by high correlation with the ACL-RSI (r=0.71) and low correlation with Multi-dimensional health locus of control (MHLC) subscales (r=-0.18 to 0.03) in an ACLR population.[120,133] The K-SES was found to have good responsiveness covering the time period from ACLR through rehabilitation, with significant increases in score over the one year period.[135] Patients with higher baseline PA level, measured using the TAS,

also had higher K-SES pre-operatively.[135] Good physical performance, both at 1 year and 5 years after knee injury or surgery, was found to have a small positive impact on future knee-related self-efficacy at 6 years.[136] The relationship between K-SES and objective PA has not been evaluated, neither has the K-SES been applied in a knee injury population other than ACL rupture. At present, the K-SES has only been used in the Swedish cultural context.

1.4 Health outcomes after knee injury

Overall, the long-term health outcomes for individuals after a knee injury are variable depending on the injury severity and specific structures injured. For individuals who have surgery for recurrent patellar dislocation, the pooled risk for further complications is low at roughly 4%.[38] Similarly, clinical and functional outcomes are generally satisfactory for younger individuals after meniscal repair for a traumatic lesion.[137] However, systematic reviews have found sub-optimal quality of life for people following both operative or non-operative management of ACL rupture.[108,138] One study reported that only 44% of patients were satisfied with their knee function at approximately 3 years after ACLR.[139] Recurrent injury rates are particularly high after ACLR, especially for younger, more active individuals.[140] The odds of youth becoming overweight or obese is also greater than age-and-sport matched controls who have never had a knee injury.[141] Most critically, having a traumatic knee injury is the single biggest predictor of developing PTOA in young or middle adulthood.[4]

1.4.1 Recurrent injury

Unfortunately, after sustaining a primary knee injury, the probability of suffering a future recurrent injury is exceedingly high. Meta-analysis suggest nearly 1 in 4 young athletic individuals who return to pivoting sports after ACLR will sustain a second rupture (10% ipsilateral recurrent injury; 12% subsequent contralateral injury).[140] Menisci, which are often torn concurrently with an ACL rupture; can alternatively be injured subsequently both with non-operative and operative ACL management.[94,142] Patellar dislocations in adolescents are often associated with repeated instability, resulting in 'giving way' episodes, functional limitations, and further damage to adjacent structures until they are surgically managed.[143] Fortunately, after patellar stabilization surgery there is low incidence of recurrent instability, post-operative apprehension, and reoperations .[38] Importantly, across all secondary knee injuries, the most vulnerable time with the highest risk for local or recurrent injuries is during the tenuous RTS phase, within 2 years of initial injury or surgery.[33,140,144]

Factors found to be associated with increased risk of recurrent ACL injury include younger age, female sex, making an early RTS, returning to participation in pivoting sports, and receiving an allograft.[144–148] Numerous registries have found that younger patients, under 19 years of age, have higher rates of ACLR revision, as well as bilateral reconstructions compared to their older counterparts.[145,149] Sex comparisons show that females athletes have up to four times greater ACL recurrent injury rates than males in the one year period after being medically cleared to RTS.[144] Participating in an accelerated rehabilitation program and making an expediated RTS has also been shown to

be highly predictive of sustaining a second ACL rupture in younger athletes.[147] In fact for each month that RTS can be delayed, the recurrent injury rate was reduced by 51% up until 9 months post-surgery, after which no further risk reduction was found.[104] Patients are more likely to have secondary meniscal surgery after ACL injury if they return to high-level sport or have knee laxity.[33] The role of ACLR in preventing subsequent local meniscus injury is unresolved,[150] with reviews stating conflicting conclusions.[151,152] In one landmark randomized controlled trial of early ACLR versus rehabilitation plus optional delayed reconstruction, over 50% of participants had meniscus surgery within 5 years, regardless of treatment group.[94] However, other studies report delaying operative treatment for ACL injury is associated with higher rates of meniscal injury.[142]

Unsurprisingly, longer-term health outcomes after revision ACL surgery are not optimistic. One large national ACLR registry with 24,000 patients found that those who had undergone revision surgery had poorer KOOS and EQ-5D scores at five years compared to those who had a single unilateral ACLR.[145] Regarding the development of PTOA, there is strong evidence that the presence of a meniscus injury along with an ACL rupture significantly increases future PTOA with up to 13% and 38% prevalence of radiographic PTOA after isolated ACL injury and combined injuries after minimum 10 years, respectively.[70] For young athletes in particular, it has been hypothesized that adhering to a high quality rehabilitation program and prolonging any RTS until a minimum 1 year after reconstruction, are both important steps to lowering recurrent injury risk.[98,146]

1.4.2 Body composition

Youth who become less active subsequent to a knee injury may be vulnerable to weight gain along with adopting a permanent sedentary lifestyle. This hypothesis is supported by two recent cohort studies examining the association between knee injuries and body composition in young athletes.[141,153] Using dual energy x-ray absorptiometry (DXA) to assess adiposity, young adults with a previous sport-related knee injury had higher fat mass by over 1 kg/m^2 compared to their matched uninjured control at 3-10 years after injury.[141 153] Another study examined the association of knee injuries with subsequent changes in body composition in young females athletes and found that those who had knee injuries increased their body fat by 1.5% more than individuals without history of injury and similarly their BMI percentile increased by up to 5 units more than their uninjured peers.[153] Obesity is also a strong risk factor for the onset, progression, and symptoms of knee OA.[154] Being overweight or obese contributes to OA in two ways: biomechanically via excess joint loading and through inflammatory pathways, whereby fat releases inflammatory mediators (e.g. cytokines and adipokines) that contribute to joint damage.[155] Consequently, young adults who have had a knee injury further compound their risk of future joint disease if they gain excess body weight.

1.4.3 Returning to sport

RTS after knee injury is a complex, multi-faceted process. Within the context of contemporary health care, RTS should be a shared collaborative decision with input from various stakeholders (physician, physiotherapist, and coach) while maintaining an athlete-centered perspective.[16] Many consider RTS to be a milestone indicative of

successful rehabilitation and full recovery following knee injury.[16,38,114] Theoretically, an individual should progress through an individualized rehabilitation program moving from neuromuscular exercises to sport specific training to return to practice and competition before integrating back into pre-injury sport. Experts suggest RTS be viewed as a continuum in parallel with recovery process, rather than a determination to be made at the end stage of rehabilitation.[16] Further, the transition back to sport must consider numerous biological (i.e. muscle strength), psychological (i.e. fear of re-injury), and social/contextual (i.e. re-integration with teammates) factors. Optimal RTS should be personalized and grounded in achievement of both physical criteria (e.g. limb symmetry >90% on functional tests) and athlete's psychological readiness (e.g. self-efficacy and motivation), rather than simply reaching pre-determined time points from injury or surgery.[98,156]

The prospect of successful RTS differs by type of knee injury and level of competition. After surgical management for recurrent patellar dislocation, two systematic reviews report high return to pre-injury levels of participation for youth, 84.1% and 77.3%, respectively.)[38,157] RTS is variable after isolated meniscus pathology with studies reporting rates between 22% and 61% for competitive soccer and football.[158,159] RTS rates have been most thoroughly examined in individuals who have had ACLR. A meta-analysis including 69 studies found that overall, 81% of athletes returned to any sport, 65% returned to their pre-injury level of sport, and 55% returned to competitive sport after ACLR.[21] A second systematic review with more stringent inclusion criteria included 16 studies and reported 32.9% returned to a modified sport level and 50.7%

returned to pre-injury sport level, however 17.2% did not return to any sport.[160] Much higher rates of RTS after ACLR have been reported in elite athletes (pooled RTS=83%).[161] These aforementioned RTS statistics are in stark contrast to patient expectations. Before ACLR, 91% of individuals state that they expect to RTS at the same level, with those who were younger and highly active having the greatest expectations.[162]

Generally, youth and young adults (<25 years old), have been found to have higher rates of returning to competitive sport than middle aged adults.[21] One recent study with youth under 18 years old found that nearly 80% of those who had ACLR returned to the same sport, with about 60% returning to the same or higher competitive level.[146] However, this study also reported that the timeline for RTS in youth is considerably longer and more arduous than in adults as they require more time and patience to develop the quality of their 're-athletisation' before RTS.[146] Best practice clinical guidelines suggest full rehabilitation after ACLR should take approximately 9 to 12 months, however the reality is often much longer.[163] It is prudent for young athletes to be especially cautious with RTS, given the risk of recurrent injury is especially high for those in this age group who attempt RTS before 1 year.[104,146]

1.4.3.1 Factors associated with return to sport

Systematic reviews have synthesized the evidence regarding physical, psychological, and contextual factors associated with RTS after ACLR.[21,160,164] Physically, having both higher quadriceps strength and symmetrical hopping performance have been found to be associated with RTS, whereas psychological factors including higher pre-operative knee

self-efficacy and self-motivation, higher athletic confidence, and lower fear of re-injury are all also associated with positive RTS outcomes.[21,160,164] Contextual factors related to RTS include younger age, male sex, and playing elite sport.[21] Other influences purported to decrease RTS include suffering concurrent meniscus or cartilage injury, while engaging in an comprehensive rehabilitation program is thought to make RTS more likely.[90,165] Authors of systematic reviews warn that the level of evidence supporting the role of any single physical or psychological factor for RTS remains weak.[21,160] Many studies are cross-sectional in design and in the systematic review by Czuppon et al[160] all 16 studies were classified as high risk of bias. Ardern et al[21] lamented on the number of lower quality studies in their review with 64% failing to report pre-injury sport participation levels. While less is known about the factors that affect RTS after other knee injuries that are not ACL ruptures, it is likely many of these same factors play a critical role. Clearly, with a broad range of interacting variables there is a need for further high-quality studies to examine modifiable physical and psychological factors associated with RTS.

1.4.3.2 Problems with a focus on return to sport

Given the importance bestowed upon RTS by both injured individuals and health professionals, accelerated rehabilitation protocols have been implemented without considering the potential impact of these programs on individual's longer-term health outcomes.[166] Returning to competitive sport may not be the best indicator of successful rehabilitation or indicative of future sustained healthy behaviours. Specifically, RTS involving high risk repeated cutting, jumping or pivoting movements, may not be in

youths' best long-term interests.[167] Not only may it increase the risk of recurrent injury, but it has potential to cause permanent and disabling joint damage.

Cartilage homeostasis has been found to be altered following ACLR and structural integrity may not be strong enough to cope with early RTS.[73] Cartilage and joint structures continue to heal and regenerate for up to 1 year after surgery.[73] Advanced imaging technologies show rapid deterioration of cartilage quality within a year of ACL rupture, [168] and another study reported 31% of young adults have MRI-diagnosed PTOA at 1-year following ACLR.[77] In the Alberta Youth PrE-OA study, osteophytes, full thickness cartilage loss, subchondral bone marrow lesions, and meniscal disruption were visible on MRI in 36% of the knee injury group at 3-10 year subsequent to knee injury, indicative of pre-radiographic PTOA.[106] Conversely, these changes were only seen in 6% of youth from the uninjured group.

Many youth or young adults may not wish to return to competitive sport, for reasons unrelated to their knee injury. Adolescence is a time of maturation, changing interests, and a period where individuals may choose to have greater focus on their academics or occupational goals, instead of competitive sport. Using RTS as a proxy for successful knee injury rehabilitation may result in these individuals undeservedly being classified as having poor outcomes. Conversely, some individuals who do RTS may continue to struggle with pain or functional limitations that are far from successful. Adolescence is also a period when healthy behaviours, such as daily PA, that are aligned with a positive lifestyle can be promoted and ideally integrated to become permanent aspects of daily

life. Therefore, RTS should only be considered one component of the broader construct of PA. It is paramount when evaluating successful outcomes after knee injury, both from the view of successful short-term injury recovery and promoting longer-term joint health, a more comprehensive understanding of PA participation be examined.

1.5 Physical activity in youth

PA is essential for physical, psychological, social, and cognitive health in youth.[63] There are a multitude of physical benefits including decreasing cardiometabolic risk, maintaining a healthy body weight, and promoting skeletal health.[63,169] Strong associations have also been found between PA and quality of life or well-being, as well as PA and improved mental health.[169] Sport, as one important component of PA, provides opportunity for learning social skills, enhances cognitive development, and contributes to building a positive self-concept.[170] Importantly, all PA intensities are associated with disease prevention and health promotion in youth, with higher intensities having more consistent and robust relationships with health indicators.[169] Evidence also suggests higher PA participation during adolescence supports a more active lifestyle in adulthood.[171]

1.5.1 Defining physical activity

Broadly, PA participation in daily life can be defined as any bodily movement that results in energy expenditure and includes occupational, household, and sport activities.[172] Moderate intensity PA requires an individual to perform movement with enough effort to still be able to carry on a conversation, yet their heart rate accelerates to burn three to six

times more energy than if they were sitting quietly.[173] Examples of moderate-intensity activities include brisk walking, dancing, or housework. Vigorous intensity PA includes activities that require a strenuous effort and result in rapid breathing and substantial increase in heart rate which burns six times greater energy than if they were sitting quietly.[173] Examples of vigorous PA include running, fast cycling, or aerobics.

1.5.2 Physical activity measurement

Due to the multi-dimensional nature of PA, consideration should be given to which aspects of PA are important to measure when answering a given research question. For example, the quality of PA data desired (e.g. details about activity type, intensity, frequency, and duration); the importance of the objectivity of the data and subject burden; the associated cost and time to administer; and the specific limitations unique to each tool, are all aspects that should be well thought out.[174,175] Common methods of measuring PA include self-report questionnaires, log books or diaries, direct observation, and accelerometry.

PA questionnaires vary significantly in what facets of PA they measure (e.g. mode, frequency or duration), how PA is quantified (e.g. activity score, time, or calories), the depth of PA details (e.g. inclusion of leisure and non-leisure activities; intensity classification); and how PA data are obtained (e.g. pen and paper, computerized, or interview). The TAS is one example of a validated questionnaire often used to quantify PA in individuals with a history of previous knee injury, as it is a concise method to grade work and leisure PA.[117] Questionnaires have advantages: cost-effectiveness, ease

of administration, accuracy in measuring intense activities, and ability to provide qualitative details about PA.[174] However, they rely on participant's recall abilities and may be less accurate at measuring moderate intensity activities compared to vigorous intensity,[176] as well as unduly influenced by external factors such as social desirability bias, reactivity, or complexity of questionnaire.[174] Self-report diaries ask participants to record detailed PA in real time, overcoming some limitations of questionnaires (i.e. less recall errors), however they have greater participant burden and can still be vulnerable to participant reactivity.[174] Direct observation, where an independent observer monitors and records PA, is sometimes used when PA is restricted to a contained area, such as a classroom or playground.[177] Observation can convey detailed contextual information; however it is resource intensive and the data can be difficult to quantify.

Accelerometers have seen an exponential increase in usage for monitoring PA, with the published literature expanding from 10 to 90 to 600 articles per year in the 1980-90's, 2003-04, and 2012-13, respectively.[178] Accelerometers quantify acceleration resulting from PA-associated bodily movement at a fixed point of the body, commonly the hip or wrist.[178] They are considered more objective than self-report PA, have the ability to capture large amounts of data, and are easy to administer.[175] Accelerometers have been employed in large population health studies in North America including the Canadian Health Measures Survey (CHMS 2007-2015)[19,179] and United States National Health and Nutrition Examination Survey.[180] Accelerometry data can compute PA volume at specific intensities, as well as make broad categorizations such as achievement of PA guidelines. Accelerometer strengths include: the ability to comprehensively capture all types of PA

(i.e. sport, household, and occupational demands) at respective intensities; feasibility in different populations (e.g. children), large memory capacity, and complete 24-hour day monitoring if necessary.[175] Drawbacks of accelerometry include the high costs, technical expertise and specialized software requirements, the lack of standardized data reduction protocol, and the absence of contextual PA details.[174,175]

1.5.3 Canadian physical activity guidelines

The importance of regular PA participation during adolescence and adulthood for an individual's current and future health is supported by indisputable evidence.[13,169] Canada has a rich history of producing and promoting evidence-based PA recommendations for public health.[181] The first Canadian PA guidelines for adults were released in 1998 as a partnership between the Canadian Society for Exercise Physiology (CSEP) and Health Canada, with the specific guidelines for children and youth released shortly thereafter in 2002.[181] The overarching goal of PA guidelines is to promote incorporating PA behaviours into habitual daily routines to maximize health benefits.

Recently, Canadian researchers and policymakers have taken a novel approach to create an inclusive framework that unites behaviours which were previously examined in isolation [moderate and vigorous physical activity (MVPA), light PA, sedentary behaviours, and sleep] creating the "Canadian 24-hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviours, and Sleep"[182] In these guidelines, children and youth (aged 5-17 years) are encouraged to 'sweat' by accumulating at least 60 minutes of MVPA daily, in addition to engaging in

vigorous PA and muscle and bone strengthening activities (e.g. weight bearing exercise) three days each week. Incorporating the 24-hour concept, the remainder of the guidelines encourage adolescents to 'step' to achieve light PA for several hours a day; 'sleep' for 8-10 hours per night (aged 14-17 years); and 'sit' for no more than 2 hours of recreational screen time per day. For adults (aged 18-64 years), Canadian PA guidelines recommend accumulating at least 150 minutes of aerobic MVPA every week, as well as performing muscle and bone strengthening activities minimum twice per week, with the caveat that more PA provides greater health benefit.[183] Brand new American PA guidelines predominantly align with Canadian recommendations, while even more aggressively stipulating that adults should do at least 150 to 300 minutes a week of MVPA for substantial health benefits.[184]

1.5.4 Physical activity in Canadian youth and young adults

Despite the promotion of evidence-informed targets for achieving health benefits, the vast majority of Canadian youth and adults are failing to attain recommended PA levels.[19,179] This is consistent with worldwide trends, where the WHO reports that 1 in 4 adults and 3 in 4 youth fail to meet global PA recommendations.[185] Objectively measured PA data examining Canadians, aged 5-17 years, from the CHMS (2007-2015) reports that overall 7% of children and youth achieve the recommendations of 60 minutes of MVPA on at least 6 out of 7 days a week, and that 33% achieve a weekly average of 60 minutes per day.[19] Boys are more physically active than girls, and activity levels decrease considerably with age.[19] This steep decline in PA during adolescence is concerning given the long term health ramifications of this downwards trajectory.[13,171,186] Objective

accelerometry data from a representative sample of Canadian adults also reported low levels of PA, with 15% meeting current recommendations.[179]

The annual ParticipACTION Report Card on Physical Activity for Children and Youth is the most comprehensive assessment of child and youth PA in Canada representing the consolidation of the best available, objectively measured and self-reported, evidence on PA.[15] The 2018 report card gives Canadian children and youth a D+, using synthesized data to conclude that 35% and 15% children and youth aged 5-17 years are meeting PA recommendations and complete 24-Hour Movement Guidelines, respectively.[15] Unfortunately, among all children and youth, girls aged 12-17 years have the lowest percentage meeting MVPA guidelines (14.1%).[187] One positive finding from the report is that Canadian youth received a B grade in organized sport, given approximately three quarters (77%) participate in organized PA, with those aged 12 to 17 years spending 29 minutes per day in leisure time sport and exercise.[15,188]

1.5.5 Factors associated with physical activity participation

Given the complexity of the determinants and correlates that influence PA, the Ecological Model has been touted as a comprehensive framework for understanding the multiple factors that contribute to participation.[189,190] Sallis et al. developed one such model with four domains of PA (active recreation, household activities, active transport, and occupational activities) with multiple levels of influence that are specific to each domain such as intrapersonal, environmental, and policy influences (Figure 1.3).[190] This model

helps to facilitate a holistic perspective when considering the diverse factors that are hypothesized to affect active living.

Sterdt et al conducted a systematic review of reviews that examined the correlates of PA in adolescents (aged 13-18 years) organized into five categories: demographic/biological; psychological/cognitive/emotional; behavioural attributes and skills; social/cultural; and physical environment.[191] They synthesized the results from 10 systematic reviews which included 316 unique studies, and acknowledged that the majority of research in the field has focused on individual-level factors (e.g. demographic and biological correlates), such as the positive association between PA and each of, being male, having higher socioeconomic status, and being younger in age.[191] Despite some heterogeneity, there were positive associations found between PA and achievement orientation, perceived competence, intention to be active, and self-efficacy. Other correlates, including previous PA participation, parental and friend support, and opportunities to exercise or access to facilities, all had varying degrees of supportive evidence.[191] One review found that for girls, having higher BMI was negatively associated with PA. [192]

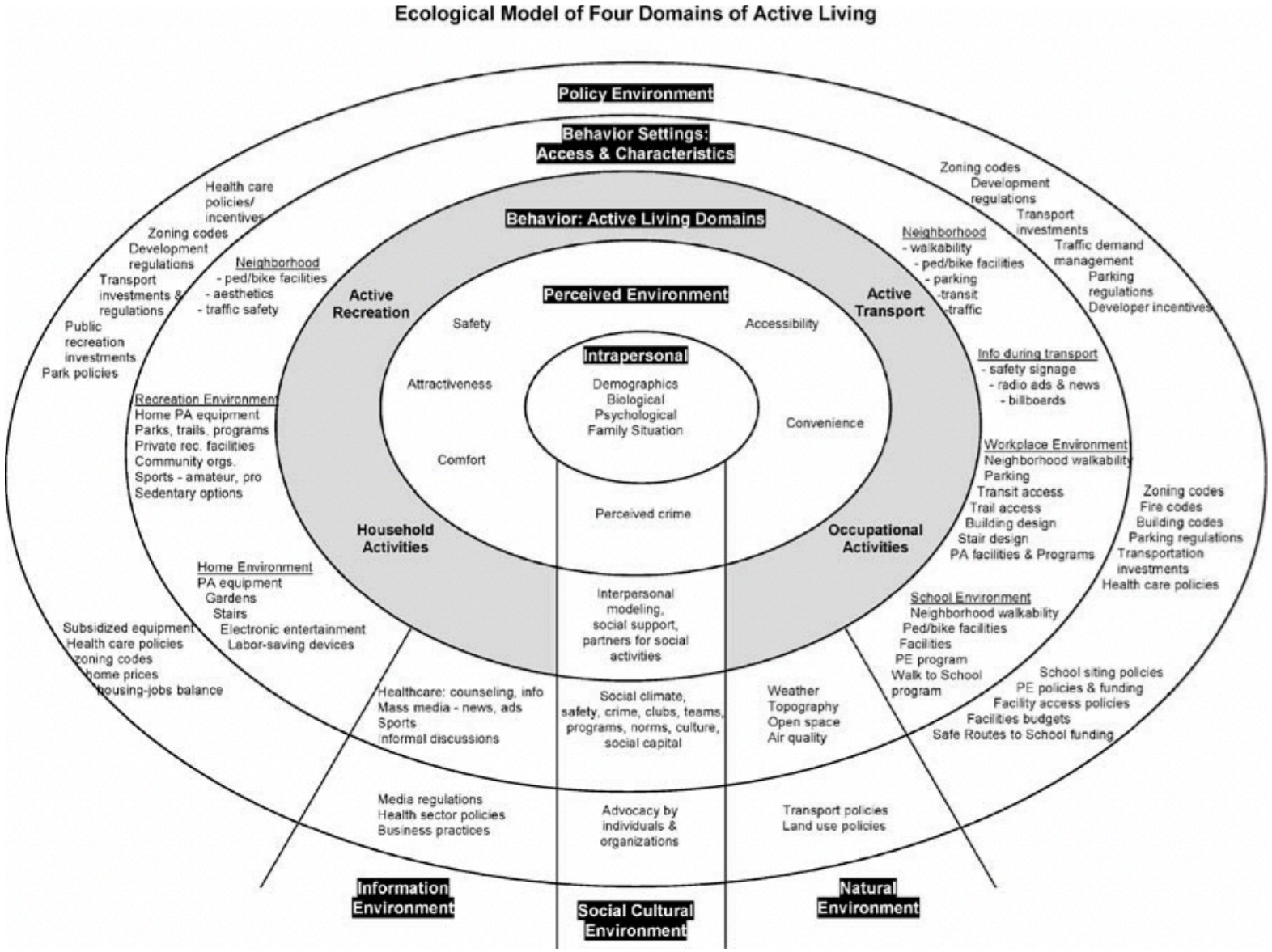


Figure 1.3 Ecological model of four domains of active living.

Reproduced from Annual Reviews of Public Health, Volume 27, Sallis, JF et al. "An ecological approach to creating active living communities", pp 297-322. 2006, with permission from Annual Review.

This holistic framework of PA determinants has not yet been applied in the context of examining PA in individuals who have had a previous knee injury. Instead, a fairly narrow perspective focusing on the intrapersonal factors that facilitate RTS, within the domain of sport and recreation, has been the focus of research. Developing an understanding of the PA patterns in this unique subgroup across all domains could provide new opportunities and targets to increase participation.

1.6 Physical activity following knee injury

Sustaining a musculoskeletal injury has been identified as a primary cause for reducing PA participation.[193,194] However, the examination of PA after knee injury has largely focused on quantifying intrapersonal factors associated with RTS within the active recreation domain, without understanding the broader context of PA. Given the indisputable health burden associated with physical inactivity,[5–7] developing a clear understanding of the effect of a knee injury on longer term PA participation is critical.

Prospective examination of PA in individuals after knee injury has usually employed self-report measures such as the TAS,[117] Marx activity rating scale,[195] or using unvalidated study-specific questions.[139] While these outcome measures have been able to provide valuable contextual details pertaining to PA, they are not designed to accurately quantify all critical aspects of PA based on the FITT (frequency, intensity, time, type) principle,[196] in a precise and reliable manner. Objectively-measured PA using accelerometry can eliminate recall errors and potential reporting bias, while providing detailed patterns of activity and precise intensity information.

Only one cross-sectional study has examined objectively-measured PA in adults who previously underwent ACLR and they reported less time in MVPA and had lower daily step count than healthy-matched controls.[197] A more comprehensive understanding of the detailed PA profiles of youth and young adults who have had ACLR is necessary in order to develop strategies and provide guidance on healthy PA participation for long term whole body and knee joint health in these individuals.

1.7 Physical activity in individuals with post-traumatic osteoarthritis

Physiotherapists play an essential role in guiding the conservative management of PTOA, aiming to manage symptoms and delay disease progression via the foundational treatments of PA, exercise, and weight management.[10,11] While these best practice guidelines were developed with older adults in mind, they are also applicable to younger individuals with PTOA. The cyclical loading and unloading of joint cartilage that occurs during exercise is healthy for cartilage and may prevent PTOA progression.[17,18] A graded linear relationship has been found between higher amounts of PA assessed prospectively and functional performance on walk tests 1 to 2 years later in people with knee OA.[198] Similarly, exercise programs focusing on aerobic, resistance, or performance-based exercises have all been found to result in reduced pain and disability in individuals with knee OA.[199] Despite the overwhelming evidence on the benefits of PA for individuals with joint problems, meta-analysis of objectively measured PA has revealed that the vast majority of individuals with knee OA (87%) fail to meet recommendations of achieving minimum 150 min per week in bouts of 10 minutes or more.[200] To date, there has been no research specifically examining PA behaviour in the PTOA sub-group of younger individuals who have a history of previous knee injury.

1.8 Critical appraisal & rationale

Despite the rising knee injury rates in youth,[32] the knowledge and understanding of the injury sequalae occurring in the time period following recovery from acute knee injury, yet before the clinical diagnosis of PTOA remains largely a 'black box' from an evidence-based perspective. There are few studies that have prospectively followed individuals who have a history of serious knee injuries beyond the one year after injury or surgery. Even fewer studies have included an uninjured (matched) control group of peers to facilitate a less biased comparison of health outcomes. Unfortunately, many studies have failed to objectively measure of key variables such as body composition or PA participation. Also there has been intensive focus on the concept of RTS, as well as the intrapersonal factors that could influence it, rather than embracing the more holistic view of PA and the wide variety of external influences that have emerged from the broader PA literature.[190] Further the vast majority of studies examining this unique post-knee injury population are quantitative in design, traditionally examining, measuring, and analyzing numerical data to investigate associations or relationships to answer specific pre-determined hypotheses.[201] Far fewer studies in this field have taken a qualitative approach, which is concerned with the nature of a phenomena (its properties, state, and character) and has an emphasis on processes and meaning.[202] These two fundamental study designs are inherently different in the types of research they address and the type of knowledge that is generated.[201] Finally, despite what has been reported about sex discrepancies in PA participation,[19] knee injury rates,[26] and RTS,[21] few studies have examined females in isolation or compared health outcomes in females to males at this critical juncture after joint injury.

Understanding health outcomes in youth and young adults after knee injuries is important when viewed from a population health perspective and through a clinical lens. Sustaining a serious knee injury at a young age, can be life changing and result in a lasting burden with significant quality of life and financial implications for an individual and society. The development of successful secondary prevention strategies that could reduce this burden are critical. In the years following a knee injury, many individuals may not be in direct contact with health care professionals. Therefore, the implementation of secondary prevention interventions may need to look beyond direct clinical care to examine more broadly public health opportunities. In order to do this, a comprehensive understanding of this post-knee injury population is necessary.

This dissertation aims to advance the evidence-base examining health outcomes following knee injury by addressing some of the aforementioned limitations that exist in the field. By focusing on knee injury youth and young adults specifically, this dissertation targets a high injury risk sub-group of the population that represents the largest future public health burden. The final study included in this dissertation further focuses specifically on female youth and young adults who have had ACLR, given they are a distinctive sub-group that may have unique health challenges in the future. To address the relative lack of qualitative studies in this field, a qualitative hypothesis-generating study formed the foundation for the subsequent quantitative studies contained in this thesis. Further, the inclusion of a control group in two of the quantitative studies facilitated a less biased normative comparison accounting for sex, age, and previous sport participation (type and competitive level.) The studies in this thesis measure and control for key variables including body composition [Fat mass index (FMI) and BMI], psychological factors, and PA. The objectively measured examination of PA encompasses not only sport and recreation

participation, but also PA that occurs during occupational activities, household tasks, and active transportation should represent a substantial novel contribution to this field.

1.9 Theme of dissertation and objectives

The broad theme of this dissertation was to advance the understanding of the critical period after a knee joint injury, yet before the onset of the disability associated with PTOA. The objective is to examine the attitudes and beliefs about PA, selected physical and psychological health-related outcomes, and PA participation of youth and young adults in the years following a knee injury. The primary overarching hypothesis was that sustaining a knee injury would have a meaningful influence on beliefs, negative impacts on health outcomes, and would result in decreased PA participation.

1.9.1 Study #1

In the first hypothesis-generating study (Chapter 2), qualitative interviews were conducted with youth and young adults who had sustained a previous intra-articular knee injury in the past 3-10 years to explore the influence of their injury on their attitudes and beliefs about PA and PTOA. These participants were a sub-set of individuals from the longitudinal historical cohort study: the Alberta Youth Prevention of Early OA (PrE-OA) study.

1.9.2 Study #2

In the second study (Chapter 3), knee confidence in youth and young adults 3-10 years after intra-articular knee injury was quantitatively compared with age and sport-matched controls without a history of previous knee injury. It was hypothesized that knee confidence would be

lower in youth who had sustained a previous knee injury compared to those who had no history of knee injury and that knee confidence would influence PA participation. This was secondary data analyses of data from the first 100 participants from the PrE-OA study.

1.9.3 Study #3

In the third study (Chapter 4), a translation and cross-cultural adaptation of the measurement properties of the Knee Self-Efficacy Scale from Swedish to English in a sample of youth and adults with a history of intra-articular knee injury in the previous 5 years was completed. Participants for this study were recruited from Glen Sather Sports Medicine Clinic at University of Alberta, Edmonton, Alberta; Fortius Sport and Health, Burnaby, British Columbia; and North Shore Sports Medicine, North Vancouver, British Columbia.

1.9.4 Study #4

For the fourth study (Chapter 5), objectively measured PA and other health-related outcomes were examined in a cohort of female adolescents, that included participants who had received ACLR in the past 1-2 years, as well as age-and-sport-matched controls without a previous knee injury. There were three main hypotheses: 1) participants who had ACLR would have lower levels objectively measured PA compared to uninjured matched controls; 2) participants who had ACLR would have higher BMI, poorer neuromuscular control outcomes, lower KOOS scores, and higher athletic identity compared to uninjured matched controls; 3) amongst those who had ACLR, participants with lower fear of re-injury, higher readiness to RTS, and higher knee self-efficacy would have increased PA and greater RTS compared to those with higher fear of re-injury, lower readiness to RTS, and lower knee self-efficacy. The exploratory objective was to

prospectively explore the association between PA and the odds of new knee injury or recurrent injury within the following year. This cohort was recruited from Orthopaedic surgeons in the Greater Vancouver region.

Chapter 2: **Attitudes and beliefs about physical activity and post-traumatic osteoarthritis in young adults following knee injury**

2.1 Background

While sport and PA participation are associated with many important physical and psychological benefits in adolescents and young adults,[169] engaging in sport is a leading cause of injury requiring medical attention in adolescents.[203] Adolescent sport injuries have negative short-term impact on health-related quality of life inclusive of increased pain and reduced physical and social functioning compared to uninjured peers.[61] At a time critical to establishing healthy life-long PA behaviours, it is estimated that up to 8% of youth drop out of sports each year after an injury occurrence or due to a fear of sustaining an injury.[62] Further, the long-term consequences of youth sport injury can include the development of PTOA,[1,3] a pathological disease characterized by chronic pain and disability with large personal and societal economic burden. [67]

Currently, the attitudes and beliefs of young adults with previous knee injury regarding PTOA and PA are largely unknown. These beliefs are important as they may shape future decisions and behaviours that could influence joint health. One recent quantitative study asked Australian and American adults, 1 to 5 years post-ACL injury about their OA knowledge and beliefs using a custom-designed survey.[204] Most respondents (70%) rated themselves as being at greater risk of OA than their healthy peers, however only half (56%) were able to correctly define OA, and two-thirds (65%) either wrongly believed that ACLR reduced the risk of OA or they did not know.

In order to develop effective secondary prevention strategies for PTOA, there is a need for greater in-depth understanding of the perspectives of young adults 3-10 years after joint injury. We hypothesize that there is a critical latency period 3-10 years after joint injury. This time span represents a period distinct from the original joint injury, where we would expect to find varying presentations of clinical and structural changes suggestive of early PTOA. This could be a unique window of opportunity for interventions for the secondary prevention of established PTOA.

2.1.1 Study purpose

The purpose of this study was to understand the influence of the injury experience on current attitudes and beliefs about PA and PTOA in youth and young adults 3-10 years after a severe sport-related intra-articular knee injury.

2.2 Methods

2.2.1 Study Design

A descriptive phenomenological study was undertaken using an inductive approach to better understand the 'essence' of young adults' attitudes and beliefs and the meaning of their lived injury experience.[205] Semi-structured interviews were conducted and analyzed concurrently using constant comparative methods.[206] Trustworthiness and creditability were fostered through prolonged engagement with the data over an extended period of time to facilitate immersion, where each interview was listened to and read multiple times; regular discussions were held with peer researchers on coding strategies, early concepts, and developing themes; ongoing reflexivity

was stimulated with pre- and post-interview memoing; and a detailed audit trail of all analytic decisions was maintained.[207]

Before data collection, a bracketing strategy was employed to acknowledge subjectivity and set aside preconceived assumptions about the research question as a method of "monitoring of self" to acknowledge and outline personal expectations, bias and beliefs.[208] It was identified that having the knowledge and perspectives of a physiotherapist may influence results and care was taken to include a researcher without clinical training as a member of the coding team to provide a different lens for viewing the data.

2.2.2 Ethics

To conduct this study ethics was granted from the Conjoint Health Research Ethics Board at the University of Calgary (ID# 25075) and the Children's and Women's Health Centre of British Columbia Behavioural Research Ethics Board (H13-00720). All participants provided informed consent at study entry.

2.2.3 Participants

Participants were recruited from within the 'The Alberta Youth Prevention of Early OA Study' (PrE-OA), a longitudinal historical cohort which examines the association between knee joint injury sustained in youth sport and early clinical, structural, functional, behavioural, and physiological outcomes associated with PTOA.[78,106] This cohort consists of 100 participants who sustained a youth sport-related intra-articular knee injury 3-10 years previously and 100 age-, sex-, and sport-matched healthy controls. Cohort participants were recruited from: previous

studies examining injury risk factors and prevention strategies in youth sport conducted at the Sport Injury Prevention Research Centre (SIPRC), University of Calgary [209–214]; the University of Calgary Sports Medicine database; or through personal distribution of study material by study investigators or participants (e.g. posters and flyers were shared with colleagues and teammates for word of mouth recruitment). Intra-articular knee injury was defined as a clinical diagnosis of knee ligament, meniscal, or other intra-articular tibio-femoral or patella-femoral injury that required a medical consultation and resulted in disrupted regular sport participation (missed one training or competitive session). Participants were excluded if they were pregnant; had been diagnosed with an arthritide other than OA; or had any current medical problem that prevented study participation (e.g. self-reported neurological or cardiac conditions that would prevent involvement in the functional testing aspect of the broader study). If participants had used a non-steroidal anti-inflammatory or received a cortisone injection within the previous 3 months, they were excluded. Lastly, sustaining a musculoskeletal injury that resulted in time loss (work, school, sport) within the previous three months also rendered participants ineligible.

2.2.4 Sampling

A purposive sampling technique was used to select participants from the 100 previously injured individuals who had experience in the phenomenon under investigation.[215] Participants were contacted either in person during quantitative data collection or by phone. Only one person who was approached to participate in the qualitative component of the study declined to be interviewed. Maximum variation sampling selected a balance of female and male participants with variation in age and a range of weekly minutes of MVPA as measured by responses to the modified Godin-Shephard Leisure Time Questionnaire (GLTQ) (Appendix G).[216] Individuals

with more substantive knee injuries (i.e. requiring knee surgery, withdrawal from most regular activities and/or sport participation at the time of acute knee injury) were targeted. This was determined through conversations with participants at the quantitative data collection session. Participant sampling was driven by ongoing analyses.[215] For example, as analyses proceeded it was determined that sampling participants with varying amounts of current PA participation was necessary. Data collection ceased when data saturation was reached such that further interviews would not contribute to the conceptualization of the phenomenon.[206]

2.2.5 Data Collection

Personal demographic information (sex, age, height, and weight) and injury details (injury type and time since injury) were collected for all participants. A modified GLTQ was self-administered to participants to quantify minutes of moderate and vigorous PA (MVPA) over a typical week (Appendix G).[216] This self-report PA instrument has been used in a similar manner in active young adults where results for MVPA were found to be moderately correlated with objective accelerometer data (r=0.40).[216] One-on-one semi-structured interviews were conducted using open-ended questions to encourage participants to communicate their own meaning to the injury experience. An interview guide aided participants in telling their stories freely without guidance from the interviewer or the constraints of a structured interview (Appendix A).[217] Questions were grouped into three topics: PA and sport, knee injury, and PTOA.

All interviews were conducted over a nine-month period (June 2013-March 2014). Fourteen interviews were done face-to-face in a private room at the SIPRC, whereas six were conducted over the phone. All interviews were recorded for analytic purposes. In-depth reflective memos,

descriptive and analytical, were done preceding each interview in preparation for full engagement, as well as after each interview to document immediate impressions including emerging themes, body language, tone, and environmental factors.[215]

2.2.6 Data Analysis

Participant characteristics including sex, age, body mass index (BMI; weight (kg)/weight (m)2), type of injury, time since injury, and weekly minutes of MVPA at the time of interview were summarized. Interviews were transcribed verbatim with pseudonyms to maintain confidentiality of participants. Data were organized using NVivo 10.0 data management software (QSR International, 2014).

Main themes were revealed inductively using a constant comparative approach.[206] This process involved three main types of coding. First, open coding examined data in discrete events to develop unique conceptual codes for ideas within the data. Secondly, axial coding compared and related codes to each other, condensing them into categories. This reassembles the data into a framework and provides coherence to the emerging analysis. Lastly, selective coding integrated the larger categories, clarifying the main themes related to the 'essence' of the knee injury experience.

All transcripts were coded independently, and a coding scheme was developed that was modified throughout the analyses as open and conceptual codes evolved. Three members of the research team coded a selection of interviews (the first three interviews were triple coded, then one every four interviews thereafter) and the team met regularly for reflective discussion to solidify

interpretations. Throughout this prolonged engagement with the data, analytic memos were kept and revisited to highlight emerging themes, make comparison, or reveal gaps in the analysis.

2.3 Results

Twenty participants (10 females) aged 16 to 26 years of age were interviewed. Interviews were typically 45-75 minutes in length. Demographic and injury details including weekly minutes of MVPA participation are presented in Table 2.1. There were 4 main themes (Acceptance, Resiliency and Determination, Knee Confidence, and Athletic Identity) and 13 sub-themes. Each sub-theme is described briefly and illustrated with a supportive quote in Tables 2.2-2.5. Additional quotations from participants are available in Appendix B.1-B.4.

Table 2.1 Qualitative phenomenological study: participant characteristics (n=20)

Female, n (%)	10 (50)
Age, years med (range)	22.3 (16.5-26.4)
Years since injury, med (range)	7.3 (2.9, 9.9)
Injury Type, n (%)	
ACL/PCL rupture	11 (55)
Meniscus	6 (30)
Other (ligament, fracture, patella dislocation)	3 (15)
Surgery, n (%)	17 (85)
BMI (kg/m^2), med (range)	24.8 (20.0, 38.9)
MVPA minutes/week, med (range)	75 (0-210)
Meeting PAG, n (%)	2 (10)
Participated in sport past year, n (%)	16 (80)

Med: meidan; ACL: anterior cruciate ligament; PCL: posterior cruciate ligament; BMI: body mass index; MVPA: moderate-and-vigorous physical activity; PA: physical activity; PAG: physical activity guidelines: adults over 18 years: 150 minutes/week MVPA; youth 13-18 years: 60 minutes/day MVPA.

Table 2.2 Acceptance theme, sub-themes (4), and participant data

FINDINGS	ILLUSTRATIVE QUOTES
SUB-THEME: Current Physical Activity Participants' previous knee injury made a substantial and lasting impact on their current physical abilities in sport. To varying degrees, they accepted the impact of the injury on their current PA participation and made adjustments accordingly.	"After the injury, now I had to go into [sport] as a different athlete" Jessica (age 23, ACL rupture, 8 years ago.) "I knew [rugby] was really not the best idea, just because the whole contact thing…but I was fairly optimistic about being able to get back to what I was doing beforehand even if I had to say kind of dull it down to less competitive." Elizabeth (age 22, ACL rupture, 6 years ago, surgically repaired.)
SUB-THEME: Psychological Aspects Participants often acknowledged a sense of frustration with acceptance that they were no longer the same athlete as before the injury.	"When I was in high school, one of my, one or two of my coaches said that I, that if I kept working at it I would have potentially the opportunity to play post-secondary basketball, but my injury kind of blew my shot at that so that's, I mean it's super frustrating, but that stuff happens." Trevor (age 22, bilateral ACL ruptures, 6 and 4 years ago, both surgically repaired.)
SUB-THEME: Current Knee Health Participants generally accepted the injury had a negative influence on their current knee health.	"I do my long runs on the weekends, I'll be sore, but nothing that I wouldn't be able to continue for a few more kilometers and then ice when I got home. I mean, I get the same pain when I'm standing on it for half an hour, right, so I for me you just learn to adjust, or get used to it, I guess." Sarah (age 24, ACL rupture, 7 and 9 years ago, surgically repaired.)
SUB-THEME: Beliefs about PTOA Many participants had accepted the possibility of future PTOA.	"[There is a] very good chance that I'll end up with like arthritis, definitely early onset arthritis, in my knee and I'm conscious of that, but I'm also not too worried about it. It's something that if it comes, I'll deal with it, I'll figure it out, but at this point in time I'll do whatever I can just to enjoy what I've got." Callum (age 21, meniscus tear, 8 years ago, surgically repaired.)

Table 2.3 Resiliency & Determination theme, sub-themes (3), and participant data

FINDINGS	ILLUSTRATIVE QUOTES
SUB-THEME: Learning Experience Many participants came to see the injury as a learning experience that resulted in personal growth.	"It was good to go through it, but it would've been better if I didn't have to. Yeah, you do learn a lot about yourself…'what doesn't kill you makes you stronger'… hopefully it does make you stronger." Jane (age 18, ACL rupture, 4 years ago, surgically repaired.)
SUB-THEME: Motivation Most participants were highly motivated and committed to recovery.	"Well I was having results like doing physio five times a week and stuff like that I was really excited to get better faster because I was supposed to be stronger than I was before. I was seeing lots of results, right. I was doing all my exercises at home and stuff like that, I was just like let's just do it, let's just do this right, because it's going to show up for the rest of my life, right? How I treat this recovery now if I start doing like sports and stuff too early it's goanna show right and like really wreck my chances for the future. So it was really important to me that I did the recoveries right." Justin (age 19, ACL rupture, 8 years ago, surgically repaired.)
SUB-THEME: Support Participants often stated the role of social support from their family, friends, and physiotherapist in promoting recovery and fostering resiliency.	"My parents are super supportive and I told my physiotherapist that my goal was to get back playing as soon as possible, so he was giving me exercises and kind of pushing me to where I needed to be. My teammates and my coaches at school were, you know, they were supportive as well and making sure that I was doing okay." Trevor (age 22, bilateral ACL ruptures, 6 and 4 years ago, both surgically repaired.)

Table 2.4 Knee confidence theme, sub-themes (3), and participant data

FINDINGS	ILLUSTRATIVE QUOTES
SUB-THEME: Caution Many participants' greatest concern was a sense of poor knee confidence. This meant that they didn't trust their knee in certain situations and resulted in increased caution before engaging in these various activities and in some cases a fear of re-injury.	"I'd never say I'd be 100% [recovered] cause I still sort of feel it from time to time…I mean going through that whole thing, you don't want to ever go through that again so you're just a bit more careful…it's still kind of in the back of your head." Alistair (age 21, ACL rupture, 6 years ago, surgically repaired.)
SUB-THEME: Awareness Participants discussed having an increased awareness of their knee both during PA and generally throughout the day.	"It did shift my perspective a little bit as to how I have to watch myself a little bit differently now…it makes you reconsider every time you go out and do something because you always have to be conscious of what you could do to maybe hurt yourself again or maybe what risks you want to take when you're doing different sports." Callum (age 21, meniscus tear, 8 years ago, surgically repaired.)
SUB-THEME: Recovery & Return to Sport Participants had varied levels of confidence in considering if they had fully recovered from their knee injury and its impact on their return to sport.	"I do think about it, to say that it never crossed my mind would be lying but, you know, it's never stopped me from sports…I'm conscious that is a problem but I'm not worried about it enough to stop myself." Justin (age 19, ACL rupture, 8 years ago, surgically repaired.) "I didn't go at it anymore, like I retired from that event just so I wouldn't, I didn't want to risk injuring my knee again. It wasn't really worth it to me." Amy (age 25, ACL rupture/meniscus, 7 years ago, surgically repaired.)

Table 2.5 Athletic Identity theme, sub-themes (3), and participant data

FINDINGS	ILLUSTRATIVE QUOTES
Athletic Identity SUB-THEME: Sense of Self as Athlete There were contrasting perspectives on the degree to which participants still saw themselves as athletes.	"I still consider myself an athlete cause, I keep myself in shape wise to do things. There's not anything I cannot pick up and do." Nick (age 26, patellar dislocation, 8 years ago.) "That would have been the last point I would have considered myself an athlete: the day that I chose that I couldn't play anymore because my knees were giving me too much trouble." Justin (age 19, ACL rupture, 8 years ago, surgically repaired.)
SUB-THEME: Change in Importance of Sport Most participants acknowledged a shift in the importance of sport in their lives due to the knee injury as well as other factors such as increased interest in traveling or greater career focus.	"I've kinda stopped my whole sports and training and so for the last two years, I've just pretty much strictly been going to school. I've played a little bit of hockey, every once in a while with some friends, but ah, yeah, other than that, it's been pretty low key now." Alistair (age 21, ACL rupture, 6 years ago, surgically repaired.) "I don't have like as big of a competitive drive anymore…like things change and getting more career focused and focused on like doing other things like volunteering." Amy (age 25, ACL rupture/mensicus, 7 years ago, surgically repaired.)
SUB-THEME: New Roles in Sport As part of this change in athletic identity, participants discussed shifting from team sports to more individualized sports or engaging in new sport roles, such as coaching or refereeing.	"The switch from team sports more to individual kind of training and personal goals rather than like you know part of that sort of team political organization kind of thing and not like I don't play for any club I haven't played for any clubs or anything recently. I don't know if I'll go back to rugby just cause I don't want to get injured again but, yeah, so I guess the idea of being playing on a team has switched now to just being athletic for myself." Matthew (age 21, meniscus tear, 4 years ago, surgically repaired.) "I am reffing basketball, I coach basketball at a high school, and I also play intramural basketball at the university." Sam (age 22, ACL rupture, 9 years ago, surgically repaired.)

2.4 Discussion

This qualitative study is an in-depth exploration of the knee injury experience from the perspective of youth and young adults 3-10 years after a sport-related intra-articular knee injury. Four main themes were revealed that transcend an individual's attitudes and beliefs regarding PA and PTOA. Participants expressed a sense of acceptance of the injury's influence on their current PA and knee health as well as the potential for future PTOA. Yet, they had motivation and determination to meet this acceptance with resiliency, often treating the injury as a learning

experience and developing a newfound appreciation for their health. Knee confidence emerged as a significant concern for RTS, where increased caution and awareness of the knee highlighted the ongoing impact of the injury and underlying fear of re-injury. Finally, the fluid nature of athletic identity was emphasized as part of an evolving sense of self, influenced by both a shift in the importance of sport and the adoption of new sport roles. These findings will be useful to inform the development of future strategies to encourage sport and PA in this population. For example, this study highlights the need for an intervention to improve knee confidence in this population. In addition, it exposes the fluidity of athletic identity that provides new perspective to considerations surrounding RTS after knee injury.

The self-determination theory, is a theory of human motivation and personality that focuses on three innate psychological needs, namely competency, autonomy, and relatedness, that are postulated to be necessary for enhancing self-motivation and health.[218] The fulfillment of these three basic needs is what facilitates autonomous motivation along with optimal growth and development. Some of the key findings of the current study can be interpreted through the lens of the necessity of fulfilling needs from the self-determination theory to feel as though one has had a successful recovery 3-10 years following knee injury (figure 2.1.)

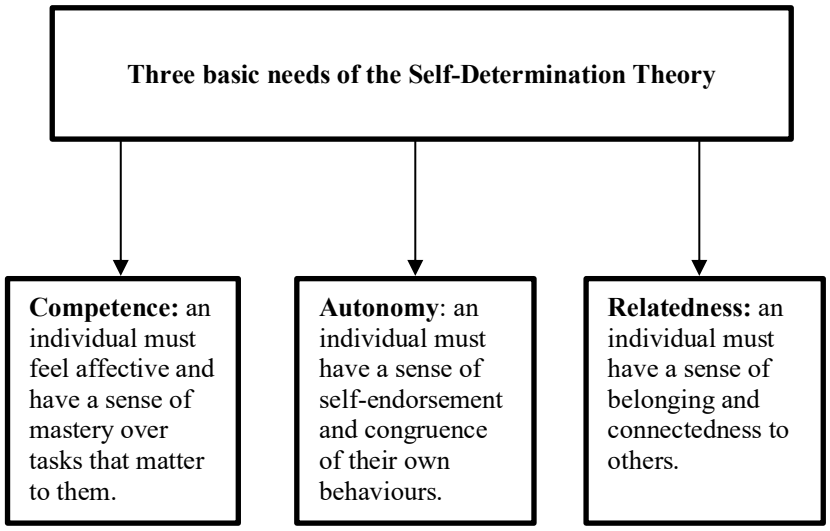


Figure 2.1 Three needs of the Self-Determination Theory

Discussed in the theme of acceptance, participants adjusted their personal expectations to a new threshold of competency, or a sense of proficiency,[219] with their current sporting ability. The self-determination theory would suggest that individuals must feel competent and have a sense of mastery with their level of sport and PA participation. Generally, participants appeared to express primarily positive emotions with this new level of competence. Previous research has found that although athletes tend to experience positive emotions as their rehabilitation progresses, anger, frustration, and boredom appear at re-entry to sport.[65,219] The findings of the current study suggest there may be a further positive psychological shift in emotions associated with acceptance of their longer-term sport capabilities as they move beyond the RTS phase and adjust to a new PA reality. These findings align with a recent qualitative study examining quality of life in individuals 5-20 years subsequent to ACLR.[220] The authors suggested that 'adaption and acceptance' was a key theme with participants aligning their lifestyle with feelings of acceptance and satisfaction. Taken together with our findings, this suggests that acceptance of

PA at new level of competence is a key component of the long-term recovery process after a substantive knee injury.

Participants in the current study shared varying degrees of trouble with knee confidence, which may threaten their sense of competency and thus be a source of distress. Previous studies reported knee confidence and fear of re-injury as significant concerns for athletes returning to sport after injury.[219,221,222] A qualitative study examined factors affecting psychological readiness to return to sport and found confidence was an important factor influenced by trust in rehabilitation providers, social support, and achievement of clinical outcomes.[64] The importance of knee confidence in the current study suggests athletes may not be reaching the appropriate level of psychological readiness for sport if they remain bothered by confidence years later. Quantitative studies have examined knee confidence in individuals with OA and found it to be associated with both self-report outcomes and objective measures.[131,132] In a cohort of individuals 5-12 years following ACL reconstruction, Hart et al found those with OA had significantly worse knee confidence than individuals without OA ($p=0.01$) and that poorer knee confidence was associated with worse symptoms ($p=0.001$) and performance on functional tests ($p=0.01$).[223] Knee confidence may be a persistent problem after injury that is also present before the development of symptomatic OA. Knee confidence beliefs may influence decisions about PA, including sport choices and the amount and intensity of participation. Knee confidence could be cultivated by physiotherapists through ensuring the athlete achieves high physical standards before attempting return to sport,[64] fostering a trustful relationship with the athlete,[224] ensuring adequate social support,[225] and connecting the athlete with a sports psychologist when necessary.

With regards to personal autonomy, participants had conflicted perspectives on their long-term PA and joint health. In the self-determination theory, autonomy is characterized as an internal locus of control.[218] Participants expressed determination to engage in PA and sport and to 'not let [their knee] stop them,' reflecting a high degree of personal autonomy. However, many also suggested future PTOA was inevitable and largely out of their control, indicating a lack of autonomy. Misconceptions about PTOA knowledge and risk have been reported by Bennell et al. who found 65% of adults with a 1-5-year history of ACL injury responded incorrectly either that the ACLR reduced the risk of PTOA or that they did not know its outcome.[204] Individuals may require targeted education about their true PTOA risk and joint health strategies that could be effectively delivered by physiotherapists.

The concept of relatedness in the self-determination theory refers to a sense of connectedness and belonging in the social world.[218] In the resiliency theme, participants expressed the key support from parents, teammates, and physiotherapists. While not directly conceptualized by the Self Determination Theory, participants suggested their perception to their sense of self-concept as an athlete had evolved. This concurs with previous authors who suggested that the self is flexible and malleable, and susceptible to developmental and situational influences.[226] Specifically, our findings suggest athletic identity changed in most participants after their injury, influenced by the injury experience, maturation, and shifted life priorities. Previous studies reported decreases in athletic identity with increasing age, career investment, and during the short-term recovery from injury.[227–229] The current study is the first to examine athletic identity in the context of its implications for long-term injury recovery.

The importance of adolescence as a time of exploration, discovery, and self-learning should be considered when interpreting these findings. Many participants stated gradual changes in their perspective of sport compared to their pre-injury selves that was unrelated to the injury. Many had switched from team sports to individual sports. Various reasons for altered athletic identity included time management, availability of sport opportunities, and personal motivations. This theme highlights that examining return to competitive sport after a prolonged injury period during adolescence may not always be the most appropriate or accurate measure of successful recovery. Physiotherapists may wish to emphasize the importance of sport and PA as an enjoyable lifelong pursuit, rather than focusing on returning to the previous competitive level of sport.

2.4.1 Limitations

There are a number of limitations to consider when interpreting these results. Potential participants who had used a non-steroidal anti-inflammatory; received a cortisone injection; or sustained a significant musculoskeletal injury, within the previous 3 months were excluded from the larger quantitative study due to certain components (i.e. bio-marker blood work, functional testing). Consequently, this qualitative sample (recruited from within the quantitative study) may be representative of individuals with less pain and possibly better outcomes than the average person following a knee injury. These inclusion/exclusion criteria could have attracted participants who are more satisfied with their knee injury outcomes and biased our qualitative findings in a positive direction. Youth with knee injuries were recruited from an athletic population, limiting the transferability of findings to other less active populations. The attitudes and beliefs of older adults or less active individuals may be different than what was revealed

here. Some questions (e.g. “tell me if there was an upside to your injury experience”) in the semi-structured interview guide may have positively biased participants’ responses. The interview guide was modified on an ongoing basis to include these more specific questions based on: i) early participants’ initial confusion with more broadly phrased questions (i.e. tell me about your injury experience); ii) early participants' emphasizing the positive aspects of their injury experience. In addition, it was beyond the scope of this study to examine the potential influence of different types of knee injuries on the outcomes revealed. For example, future studies may wish to explore how knee injuries treated with surgery or those with longer recovery times (i.e. ACL rupture) influence findings compared to injuries with shorter recovery times (i.e. patellar dislocation). While, trustworthiness and creditability were fostered through various means, it is possible further insight into attitudes and beliefs of young adults with knee injuries could be uncovered with further data collection and analysis. A proportion of interviews (30%) were conducted on the telephone, preventing observation of nonverbal cues and possibly creating challenges in building rapport. Fortunately, previous work has found that the themes revealed in both face-to-face and telephone interviews are similar.[230]

2.4.2 Clinical implications

It is encouraging that many participants had embraced a new level of competence in sport and continued to engage in PA to some degree. However, physiotherapists may provide further education and guidance to promote PA and long-term joint health. As well, knee confidence could be more specifically targeted during rehabilitation using a structured, progressive program with individualized goals for achieving sport specific milestones with referral to other specialists when needed. Given the association that has been found between knee confidence and OA in

previous work, future research is needed to examine if it may be an important modifiable risk factor for future PTOA. There appears to be a knowledge gap surrounding awareness of PTOA in this population. Physiotherapists are perfectly positioned to provide guidance, knowledge, and care in the gap between acute injury rehabilitation and PTOA diagnosis.

2.4.3 Future directions

This study provides unique insight into the long-term attitudes and beliefs about PA and PTOA in youth who have had a knee injury. While it was not a conceptual fit for all of the study themes, the self-determination theory provides a useful framework for interpretation of some of the findings. The results illustrate that the knee injury made a significant and lasting impact on young adults during their formative adolescent years. Clinicians should consider these themes of acceptance, resiliency and determination, knee confidence, and athletic identity when working with this population. These findings mean that there may be opportunities to greater improve health outcomes by addressing knee confidence and educating these individuals about PA options as well as their future risk of PTOA. Future work should further explore the importance of psychological factors after knee injury and how these factors may influence behaviours, which in turn may impact the progression of PTOA in this high-risk population.

Chapter 3: **Knee confidence in youth and young adults at risk of post-traumatic osteoarthritis 3-10 years following intra-articular knee injury**

3.1 Background

While PA participation and sport are considered essential for healthy adolescent development,[63] injuries sustained during these activities can have serious long-term consequences, including the development of PTOA.[1,3] Meta-analyses indicate that the relative risk of developing PTOA within 10 years of a significant knee injury is 3.9 (95% CI; 2.7, 5.6).[71] PTOA onset occurs in young and middle-aged adulthood when the impact of the disease on quality-of-life and work productivity can be devastating and costly at both individual and societal levels.[88] Representing 12% of the overall OA incidence, the aggregate annual financial affliction of PTOA in the United States is estimated at $3.06 billion.[86] Given this vast burden associated with PTOA, it is imperative to investigate and understand potentially modifiable risk or protective factors that could influence the long-term consequences of knee injury in high-risk PTOA populations in order to develop strategies aimed at delaying or preventing progression to PTOA.

Knee confidence is one potentially modifiable factor that has been previously examined in individuals with OA and those at increased risk of OA. These studies have reported that up to 99% of individuals with knee OA are bothered by knee confidence.[131,132,231] Further, low knee confidence in individuals with knee OA is associated with poorer self-reported outcomes (i.e., increased fear of movement, greater pain on walking, and poorer general health),[223] and reduced physical function (i.e., lower quadriceps strength and increased dynamic valgus-varus joint motion)[131]. Accordingly, it has been postulated that a lack of knee confidence may be

synonymous with low self-efficacy and result in decreased engagement in various PA behaviours in persons with OA.[231] Therefore, it is possible that lowered knee confidence may have a role in the development, trajectory, and symptomatic severity of PTOA via its influence on PA participation.

In adults (34-56 years) with a history of ACL rupture, knee confidence was poorer ($p=0.01$) in those with symptomatic radiographic OA compared to those without any OA symptoms or radiographic changes.[223] Further in another study, 70% of adults three years after ACLR reported being bothered by knee confidence, with lower confidence being related to reduced muscle power and hop performance.[232] In the current study it was hypothesized that youth and young adults with a history of injury would have lower knee confidence than their uninjured peers. Knee confidence may act as a psychological barrier in RTS decisions and impact current and future PA participation that could have long-term implications for PTOA development and symptom management. Further in the longer term, having a history of a traumatic injury, which underlies PTOA development that is not necessarily a precursor to other sub-types of OA, may have a unique influence on knee confidence in this OA sub-type, compared to the overall OA population.

The construct of knee confidence has yet to be examined in a prospective fashion in youth and young adults with a history of knee injury in relation to an uninjured comparison group. Knee confidence warrants special examination in this age group for multiple reasons. It is unknown if knee confidence concerns may be a greater or lesser problem in youth and young adults compared to middle and older aged individuals. Further, if knee confidence is a problem in youth

and young adults, it may influence their choices for sport and PA participation in the longer term, which is important given that adolescence is a time when lifelong health behaviours are shaped.[171] If knee confidence is indeed a modifiable treatment target for PTOA it should be addressed at the earliest possible stage before the development of more severe joint disease. As well, the influence of PA participation and body composition (factors directly linked to OA)[155,198] on the relationship between injury history and knee confidence have yet to be examined.

3.1.1 Study purpose

The purpose of this study was to examine knee confidence in youth and young adults, aged 15 to 26 years old, with a history of youth sport-related intra-articular knee injury in comparison to age, sex and sport matched uninjured controls, controlling for the potential confounders of PA and body composition.

3.2 Methods

3.2.1 Study Design

This analysis involves the first-year data (June 2013-April 2015) from the PrE-OA longitudinal historical cohort study. In this study, 100 youth and young adults who sustained a youth ($\leq$18 years) sport-related intra-articular knee injury in the past 3-10 years and 100 age-, sex- and sport-matched (at the time of injury) uninjured controls are being followed annually on a diverse range of outcomes.[78,106]

3.2.2 Ethics

Ethical approval for this study was received from Conjoint Health Research Ethics Board at the University of Calgary (ID# 25075) and the Children's and Women's Health Centre of British Columbia Behavioural Research Ethics Board (H13-00720). All participants provided written informed consent at study entry.

3.2.3 Participants

Participants were recruited from three sources: previous studies examining injury risk factors and prevention strategies in youth sport conducted at the University of Calgary;[209–214] the University of Calgary Sports Medicine Centre database; or through personal distribution of study material by study investigators or participants. Injured participants had a previous history of intra-articular knee injury, defined as a clinical diagnosis of knee ligament, meniscal, or other intra-articular tibio-femoral or patella-femoral injury that required a medical consultation and resulted in missed sport participation. Injury diagnoses were obtained from injury report forms (completed by physiotherapists) or medical records (from physician clinical examination) and confirmed by the participant. At study entry, injured participants were considered 'at high risk of OA' compared to uninjured participants but were not screened for the presence of PTOA. Uninjured controls reported no previous time loss from sport due to knee injury. Exclusion criteria for all participants included pregnancy, non-steroidal anti-inflammatory use, cortisone injection or a musculoskeletal injury that resulted in time loss (work, school or sport) within the previous 3-months, diagnosis of other arthritides, or any current medical problem that prevented participation in the functional testing aspect of the study.

3.2.4 Data Collection

All data were collected in one testing session at the University of Calgary. Participants had their height (cm) and weight (kg) measured, underwent a DXA scan, and completed a study questionnaire (demographic details, medical and knee injury history [if applicable]), the KOOS (Appendix F),[116] and a modified GLTQ (Appendix G).[216]

The KOOS is a self-report outcome measure developed to examine knee-related symptoms and function, with validated scoring in active individuals with a knee injury or OA consisting of 42 items in five subscales.[116] Knee confidence was assessed using question 3 from the KOOS knee related quality-of-life subscale: "How much are you troubled by lack of confidence in your knee?" Responses on the 5-point Likert scale were dichotomized into 'bothered' (mildly, moderately, severely, or extremely) or 'not at all bothered.' This question has been used previous to quantify knee confidence in numerous studies.[131,132,223,231]

Self-reported total weekly minutes of PA participation (strenuous, moderate, and mild intensities) was assessed using a modified GLTQ.[216] The correlation between objective accelerometer data and a similarly modified GLTQ for one week recall of moderate, vigorous, and MVPA were 0.30, 0.50, and 0.40 respectively, demonstrating adequate validity.[216] It was decided that total PA best represented the most comprehensive measure of PA, compared to a variable that included only MVPA, therefore minimizing residual confounding by PA in the relationship between injury history and knee confidence.

BMI (kg/m^2) was derived from anthropometric measurements of participants' height (to the nearest 0.1 cm; shoes removed) and body mass (to the nearest 0.1 kg), assessed using a medical scale and stadiometer (Model 402KL, Pelstar, USA). BMI is a well-known measure to describe participants' body composition within a sample by giving a crude indication of adiposity. However, it fails to distinguish between fat mass and lean mass, which can be problematic in an athletic population. Given there is a specific link between obesity, defined as excessive fat mass that may impair health,[233] and the development of OA,[234] a more accurate measure of fat, fat mass index, was justified to include in the main analysis.

Fat mass index (FMI; kg/m^2) was calculated from whole body composition scans acquired with a Hologic Discovery (Hologic Inc, Marlborough, MA) DXA scanner with Discovery QDR software. The scanner was calibrated daily using a phantom containing composites of bone, fat and lean tissue. Participants were positioned supine on the scanner bed according to the manufacturer's recommendations and instructed to remain as still as possible for the duration of the scan. All procedures were consistent with the official positions of the International Society for Clinical Densitometry.[235]

3.2.5 Statistical analyses

Demographic characteristics (i.e., sex, current age, and BMI) and knee injury details (i.e., age at injury, injury type) were summarized using descriptive statistics (frequency and proportions or medians and range) and mean within-pair differences [95% CI] were used to compare outcomes between study groups. In separate models, unadjusted conditional logistic regression (OR; 95% CI) was used to examine the association between injury history and knee confidence, as well as

between injury history and each of FMI and PA in order to understand the role of these variables as potential confounders. Note, the association between injury history and FMI has been previously examined in this cohort, however FMI was felt to be conceptually important in the relationship between injury history and knee confidence, and thus the bivariable analysis was repeated for completeness in the current paper.[141] FMI and PA were investigated for possible colinearity. Lastly, multivariable conditional logistic regression was used to assess the association between injury history and knee confidence while controlling for FMI and PA. Analyses were considered statistically significant if 95% CI did not include 1 and p-value was <0.05. Statistical analyses were performed using SAS version 9.3 (Cary, NC, USA).

3.3 Results

3.3.1 Participants

Baseline characteristics (n=200) are summarized in Table 3.1. The median (range) age of participants was 22 (15-26) years and 110 (55%) were female. Thirty-three percent of the injured participants sustained their injury participating in soccer and the remaining injuries came from a wide variety of sporting environments (i.e., hockey, basketball, American football, volleyball, rugby, running, baseball, downhill skiing and figure skating). Amongst those previously injured, the median age of injury was 16 (9-18) years and the median time between injury and follow-up was 6.9 years (range 3-10). Of the 100 injured participants, 17% had patello-femoral injuries (subluxations), 13% had a grade I to II Medial or Lateral Collateral Ligament sprain, or grade I or II ACL sprain, 15% had isolated meniscal injuries and 54% experienced grade III ACL sprain (67% with concomitant meniscal injuries and all were reconstructed).

Table 3.1 Participant characteristics (n=200)

	Uninjured n=100 median (range)	Injured n=100 median (range)
Sex (% female)	55	55
Age (years)	22 (15-26)	22 (16-26)
Height (cm)	171.8 (152-195)	173.0 (156-199)
Body Mass (kg)	71.6 (49.5-100.7)	74.9 (50.2-105.5)
Age at injury (years)	n/a	16 (9-18)
Injury to follow-up (years)	n/a	6.9 (3-10)

Cm: centimetres; kg: kilograms

3.3.2 Clinical outcomes

Descriptive statistics and within-pair differences for KOOS subscales, weekly PA, BMI, and FMI are summarized in Table 3.2 and the distribution of participants' responses to the knee confidence question is shown in Figure 3.1. Overall, 49% (95% CI; 39.0, 59.0) of the previously injured participants, reported being bothered by knee confidence to some degree, compared to 12% (95% CI; 5.5, 18.5) in the uninjured group. Although there was no difference in weekly minutes of PA between groups, injured participants had higher BMI (mean within-pair difference 1.7 kg/m^2, 95% CI 0.94, 2.63) and FMI (1.05 kg/m^2, 0.53, 1.57) than the matched controls.

Table 3.2 Summary of descriptive statistics by study group and pair difference

Outcome		Uninjured¶ n=100	Injured¶ n=100	Matched Pair Difference§	P-value
KOOS Sub-scales					
	Pain	100 (69,100)	89 (53,100)	-4.9 (-7.0,-2.7)*	<0.01
	Symptoms	96 (64,100)	86 (32,100)	-8.1 (-11.2,-5.0)*	<0.01
	ADL	100 (87,100)	99 (63,100)	-2.8 (-4.2,-1.4)*	<0.01
	Sport/Rec	100 (75,100)	94 (47,100)	-5.8 (-7.8,-3.7)*	<0.01
	QofL	100 (83,100)	92 (64,100)	-8.3 (-10.2,-6,3)*	<0.01
Physical Activity (min/wk)		135 (22.5-420)	120 (0-510)	-6.4 (-28.9, 16.2)	0.58
BMI (kg/m^2)		23.5 (18.1, 31.3)	25.0 (18.9, 38.9)	1.8 (0.9,2.6)*	<0.01
FMI (kg/m^2)		4.6 (2.1, 9.3)	5.6 (1.7,16.4)	1.1 (0.5,1.6)*	<0.01

¶values represent median (range); *statistically significant

§value represents mean within pair difference: injured – uninjured (95%CI)

KOOS: Knee Osteoarthritis Outcome Score; ADL: activities of daily living; QofL: knee-related quality of life; min: minutes; BMI: body mass index; FMI: fat mass index

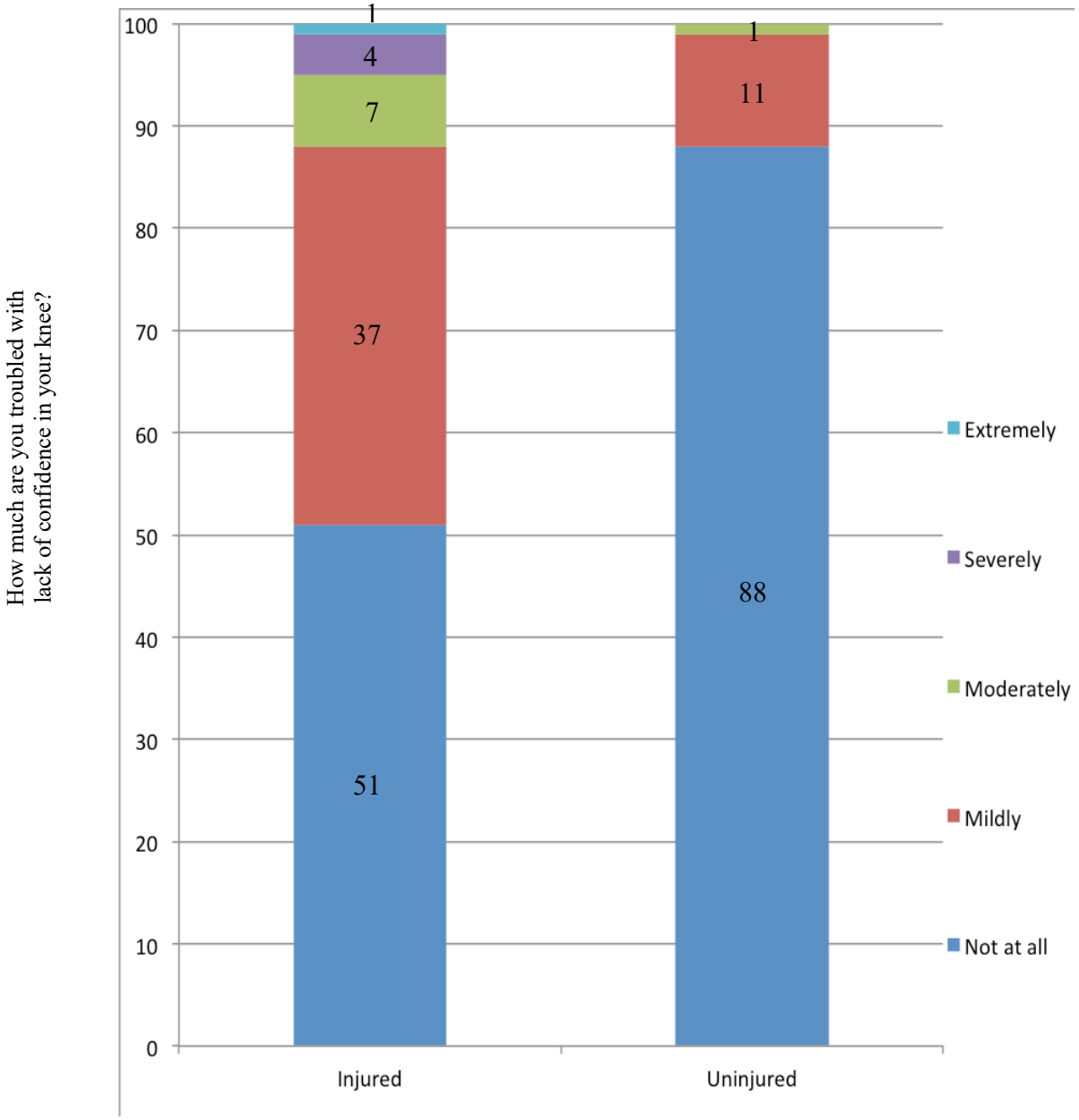


Figure 3.1 Participants' [injured (n=100) and uninjured (n=100)] response to the question: "How much are you troubled by lack of confidence in your knee?" question 3 from the knee injury and osteoarthritis outcome score (KOOS), quality of life subscale

The bivariable OR between potential confounding variables and knee confidence were not statistically different from 1; FMI [1.2 (95% CI 0.97, 1.5)] and PA (1.0 [95% CI 1.0, 1.0]) (Table 3.3), although they were later included in the multi-variable model due to their conceptual significance and lack of collinearity. Without adjusting for any confounders, the previously

injured participants had 5.0 (95% CI 2.4, 10.2) times the odds of being bothered by knee confidence than the uninjured group. When controlling for the influence of weekly PA and FMI on the relationship between injury history and knee confidence these odds increased to 7.5 (95% CI 2.7, 21.1). In this same multi-variable model, when examining the association between each confounder and knee confidence, it was found that for every one-minute increase in weekly PA or for one unit increase in FMI, there was no change in the odds of being bothered by knee confidence.

Table 3.3 Bivariable and multivariable logistic regression examining the odds of low knee confidence

Variable	Unadjusted OR (95% CI)*	Adjusted OR (95% CI)[λ]
Group		
Uninjured	1.0	1.0
Injured	**5.0 (2.4, 10.2)***	**7.5 (2.7, 21.1)***
Physical activity (minutes/week)	1.0 (1.0, 1.0)	1.0 (1.0, 1.0)
Fat mass index (kg/m^2)	1.2 (0.97, 1.5)	0.98 (0.70, 1.4)

[§]crude relationship between each variable and knee confidence
[λ]adjusted for physical activity and fat mass index; *statistically significant

3.4 Discussion

This investigation found that almost half of all youth and young adults at high risk of future PTOA due to a 3-10 year history of youth sport-related intra-articular knee injury report being troubled by a lack of knee confidence. This translates into a 7-fold increased odds of low knee confidence compared to healthy uninjured controls. While this analysis did not find PA participation to be different between groups, individuals with a history of injury did exhibit greater FMI, higher BMI, and lower KOOS scores indicative of impaired knee-related function. This study provides preliminary evidence that lowered knee confidence and increased adiposity warrants further examination as possible precursors to future symptomatic joint disease.

It has been reported that 55% of individuals return to competitive sport after ACLR and that having a positive psychological response was a key factor in returning to pre-injury participation.[21] In a cross-sectional study of individuals 5-12 years post ACLR, Hart et al.[223] found that those with knee OA had worse knee confidence and greater kinesiophobia than those without OA. Further, poorer knee confidence has also been shown to be associated with worse knee symptoms and function.[131,132] This suggests that knee confidence may be an important component of a positive psychological response and therefore a clinically relevant treatment target during rehabilitation to promote RTS and PA. Low knee confidence may be an indication of poor structural integrity of the knee joint, potentially lacking in bone, cartilage, or ligamentous stability. Alternatively, it may be a sign of incomplete or unsatisfactory rehabilitation where advanced neuromuscular and proprioceptive skills have not been adequately trained. A third hypothesis is that low knee confidence may manifest after an individual's psychological concerns, such as fear of re-injury, have not been specifically addressed. Previous authors have suggested that individualized neuromuscular exercises aimed at improving dynamic tasks may enhance knee confidence,[132,232] although this has not yet been evaluated.

Despite knee confidence being a concern for nearly half of participants in the current study, it was not found to be associated with total PA participation. This may be due to the nature of our self-reported measure of PA, which while validated, may not be sensitive enough to pick up subtle changes in PA that result from lowered knee confidence. For example, individuals may reduce their MVPA and replace it with light PA. Further, lack of knee confidence may cause participants to switch sports (e.g. instead of returning to soccer after knee injury, they now cycle and swim). This sport-specific information was beyond the scope of the current study.

Alternatively, it may require a longer time after knee injury before knee confidence truly impacts overall PA participation. The complexity of the relationship between knee confidence and PA participation should be further examined in a youth and young adult population using different methods such as accelerometers to provide an objective measure of PA.

Knee confidence was evaluated based on the response to a single question from the KOOS quality of life subscale.[116] While consistent results of previous studies using this question have demonstrated valid scores,[131,132,223] validation should be considered an ongoing process.[236] The Knee Self-Efficacy Scale, is a comprehensive, self-report measure, with validated scores that may encompass the concept of knee confidence.[120] Knee self-efficacy refers to an individual's belief in the current and future capabilities of their knee. Self-efficacy of knee function measured at the time of ACLR has been found to be predictive of self-reported PA, knee symptoms, and muscle function 1 year later.[135] While the association between knee confidence and a global assessment of self-efficacy was not found to be significant in one previous study,[132] knee-specific self-efficacy and its relationship to knee confidence warrants further evaluation.

3.4.1 Limitations

Limitations of this study include the lack of formerly validated scores for this measure of knee confidence, as well as the inability to determine temporality of the associations between knee injury and knee confidence, given these data represents first year of data collection from the historical cohort. Further PA was quantified using a modified self-reported measure, which means the PA data is less precise than data that would be obtained through objective measurement. Further self-reported PA is vulnerable to recall errors, which could result in

under-reporting due to poor recollection or conversely to over-reporting due to social desirability bias. Additionally, the small sample size (n=100 matched pairs) limited the inclusion of further potential confounders (e.g. sex, time since injury).

3.4.2 Future directions

Future studies should seek to understand the potential underlying physical and psychological reasons why individuals have low knee confidence. Further prospective longitudinal studies are required to adequately understand the directionality of knee confidence and its potential link to the development of PTOA in a younger, post knee injury population. Finally, the effectiveness of clinical interventions that target psychological outcomes, such as knee confidence, should be evaluated both for their short-term benefits as well as and the impact of these interventions on long-term function and joint health. It is recommended that further research seeking to understand modifiable PTOA risk factors continue to examine knee confidence and its associations with other clinical outcomes with the goal of improving the joint health in this population.

3.4.3 Clinical implications

Almost half of all individuals 3-10 years following a youth sport-related knee injury are troubled to some degree by a lack of knee confidence. Clinicians should appreciate of the role of psychological factors, including knee confidence, in the acute and long-term recovery after knee injury. They should discuss concerns regarding fear of re-injury and knee confidence with their patients to determine if advanced neuromuscular exercises have the potential to improve confidence or whether specific psychological assessment and treatment is warranted. In the

future, targeted combined physical and psychological interventions could be developed and evaluated for their shorter-term impact on RTS outcomes and potentially their longer-term influence on PTOA.

Chapter 4: **Translation and cross-cultural adaptation of the English Knee Self-Efficacy Scale**

4.1 Background

Knee injuries sustained during sport participation can have severe consequences including pain, limiting function, reducing quality of life, and increased risk of developing future PTOA in the knee.[138,237,238] With rising rates of knee injury and surgery,[32] understanding best how to maximize recovery is critical in order to reduce the personal burden, as well as to minimize the longer term economic and societal impact of knee injuries.[87]

Following injury, best practice rehabilitation focuses on restoring physical outcomes such as range of motion, muscle strength, and progressive functional movement.[239] This is usually driven by the individual's expectations and goals of RTS and PA.[162] However, nearly half of individuals who have sustained an ACL rupture, one of the most common and devastating knee ligament injuries, fail to return to competitive sport after one year.[21] In the longer term, it is known that an active lifestyle is essential in preventing a myriad of chronic diseases,[240] as well as important for future joint health and possibly preventing the development of PTOA in this high-risk group.[11] Research has failed to find substantial physical differences between those who RTS and those who do not.[164] However, key psychological constructs, including fear of re-injury and decreased readiness to RTS that could play a role in sport decision-making, have been found to be altered in those who do not return.[241,242] Currently, there is a knowledge gap surrounding the specific influence and measurement of various psychological factors and how they could be potentially targeted during knee injury rehabilitation to promote full recovery and positive behaviours

including RTS and PA. The development and validation of specific PROMS that accurately evaluate key psychological factors after knee injury are critical to addressing this gap.

There are a number of PROMs that evaluate psychological constructs hypothesized to be related to RTS. The ACL-RSI scale appraises psychological readiness to RTS participation after ACLR in terms of emotions, confidence in performance, and risk evaluation.[118] The Multi-dimensional Health Locus of Control (MHLC) instrument measures people's beliefs about control of their health status in general.[243] Further, a single question from the KOOS[129] has been used in isolation as a measure of knee confidence in individuals after ACL rupture.[232] The K-SES is a measure developed in Sweden to evaluate the perceived self-efficacy in patients who have sustained ACL injuries.

The K-SES was developed based on social cognitive theory (SCT).[244] Self-efficacy refers to an individuals' belief in their own abilities to organize and execute the actions required to manage the prospective situation or task.[245] Self-efficacy is thought to be an important determinant of motivation, affect, and action. Therefore, it not only influences the course of action pursued but also the extent of effort put forth, perseverance when faced with difficulties, and the nature of a person's affective thought patterns.[246] Previous research built on the SCT has shown that high levels of self-efficacy can predict health behaviours such as dietary change,[247] pain management,[248] and exercise participation.[249] It has been hypothesized that measuring and understanding a patient's knee specific self-efficacy may facilitate targeted treatment strategies for these individuals with low self-efficacy after an ACL injury, resulting in better long term outcomes.[120]

The reliability, validity, and responsiveness of K-SES scores have been found to be good when examined in Swedish studies.[120,135] In one study, three years after ACLR, the odds of being satisfied with their knee function increased three-fold in those with higher knee self-efficacy.[139] More recently, a Swedish study reported no difference in knee self-efficacy between individuals who had ACLR compared to exercise therapy alone at six years after injury.[136] This same study also reported that good physical performance at the end of exercise therapy and at five years had a small positive impact on future knee self-efficacy.[136] To the best of my knowledge, the K-SES has only been used in a Swedish context in those who have sustained ACL rupture.

4.1.1 Study purpose

The primary purpose of this study was to translate and cross-culturally adapt the K-SES from Swedish to English, as well as to broaden the target patient population to include patients with all types of intra-articular knee injuries. Secondarily, the purpose was to examine select measurement properties of the English K-SES to determine the validity and reliability of these scores.

4.2 Methods

The Swedish K-SES consists of 22 items grouped into four categories: a) daily activities (7 items); b) recreation, exercise, and sporting activities (5 items); c) physical activities (6 items); d) knee function in the future (4 items).[120] Each item is scored by the participant on an 11-point Likert scale from 0=’not at all confident’ to 10=’very confident’. Final scores are calculated based on two subscales: perceived self-efficacy of knee function related to present time (K-

$SES_{present}$: categories a, b, & c) and perceived self-efficacy of knee function related to the future ($K\text{-}SES_{future}$: category d).

The English translation and cross-cultural adaptation of the K-SES was guided by expert recommendations[126,127] in a similar manner to other recent cross-cultural adaptations of patient self-report outcomes measures.[133,250] The final version of the translated questionnaire was produced by following the multi-stage process outlined in Table 4.1

Table 4.1 Steps in Translation & Cross Culture Adaptation Process of K-SES

Step	Action
1: Consent	Contacted & informed original scale authors of the project, obtained consent to create a validated English version of the K-SES.
2:Forward Translation	Obtained initial English version of K-SES from original authors (*V1*: informed translation). Qualified translator produced second English version of K-SES (*V2:* uninformed translation).
3:Synthesis	Synthesized the two versions to create *V1-2* with input from the original author and translator
4: Back Translation	*V1-2* back translated from English to Swedish by two native Swedish speakers. One translator with medical background and one without *(VBT1 & VBT2).*
5: Expert Committee	Multidisciplinary committee (a behavioural scientist, orthopaedic surgeon, sports medicine physician, and five physiotherapists) used all versions & materials to generate a pre-test scale (*V3)*.
Step 6: Pre-Testing	Using cognitive interviewing and probe techniques, *V3* was pre-tested for content, wording, and understanding in a sample of individuals who have had tibiofemoral or patellofemoral knee injuries in the past five years. Feedback from pre-testing was incorporated to generate pre-FINAL *(V4).* This version was approved for evaluation by expert committee.
Step 7: Evaluation	Measurement properties of English pre-FINAL K-SES were evaluated.

K-SES: knee self-efficacy scale

Adapted from SPINE, Volume 25(24), Beaton, DE et al. "Guidelines for the process of cross-cultural adaptation of self-reported measures", pp 3186-3191. 2000, with permission from Wolters Kluwer Health.

Contact was made with one of the original scale developers to discuss V1, the original English translation. A professional translator produced V2 based on the original Swedish K-SES. Back translations by two uninformed professional translators native to the Swedish language were produced (VBT1, VBT2). A multidisciplinary committee, which included a behavioural scientist with expertise in psychometrics, orthopaedic surgeon, sports medicine physician, and five physiotherapists (1 Swedish/English speaking clinician, 1 English speaking clinician, 2 research physiotherapists, and 1 clinician/research physiotherapist), met to review all K-SES versions (V1, V2, V12, VBT1, VBT2) for face validity, content validity, clarity, and cultural appropriateness. All discussion and changes were documented.

Pre-test version (V3) was tested using 'think aloud' cognitive interviews[251] in a sample of the target population. Inclusion criteria for these individuals included: sustaining a sport-related intra-articular tibiofemoral or patellofemoral injury in the past 5 years, being between 16-60 years of age, and having the ability to read, write, and understand English. During the cognitive interview, participants were instructed to talk out loud and verbalize their thought processes as they read through the instructions and answered the K-SES questions. Following a semi-structured interview guide, various probes were used to encourage feedback on wording while checking for comprehension and applicability of questions. This interview guide is available in Appendix C. All member of the expert committee approved the pre-final version of the English K-SES.

The evaluation of measurement properties of the final English version of K-SES is based on resources and guidelines developed by the CONsensus-based Standards for the selection of health Measurement INstruments (COSMIN) working group.[99,105,252]

4.2.1 Assessment of measurement properties

4.2.1.1 Participants

To evaluate the measurement properties of the English K-SES, participants were recruited from three outpatient physiotherapy clinics: Glen Sather Sports Medicine Clinic at University of Alberta, Edmonton, Alberta; Fortius Sport and Health, Burnaby, British Columbia; and North Shore Sports Medicine, North Vancouver, British Columbia. Participants were eligible for the study if they were between 16-60 years of age and had an intra-articular tibiofemoral or patellofemoral knee injury (ligamentous, meniscal, or bone-related) within the last five years. Additional inclusion criteria included: 1) injured during sporting activity; 2) injury resulted in (or will result in) minimum 6 weeks missed sport participation; 3) injury required consultation or treatment with sports medicine physician or physiotherapist; 4) ability to read and understand English; 5) access to a computer and personal email account.

Potential participants learned about the study via posters or study information flyers provided to them by a clinical physiotherapist and eligibility was confirmed by phone. Those individuals who met the inclusion criteria were emailed the informed consent information, as well as a link to online data collection. Ethics was obtained from University of British Columbia Behavioural Research Ethics Board and University of Alberta Research Ethics Board.

4.2.1.2 Data collection

Fluid Survey provided by the University of British Columbia (UBC) was used to facilitate online data collection. All participants' completed a questionnaire package that included: project specific questions (Appendix H), K-SES (Appendix D), TAS (Appendix I),[117] KOOS (Appendix F),[116] ACL-RSI (Appendix J),[118] and MHLC-Form C (Appendix K).[243] The inclusion of these questionnaires facilitated the evaluation of the construct validity of the K-SES.

Project specific questions included questions pertaining to demographic (e.g. current age) and injury details (e.g. injured structures, time since injury, surgical procedures); RTS (e.g. returned to participation = modified training/practicing; returned to play = engaged in sport but not at pre-injury level; or performance = performing at or above pre-injury level;)[16] and activity level (lower, same, or higher); and satisfaction with knee function (yes or no).

The TAS is a concise, validated method to grade work and sport activities.[117,253] TAS ranges from 0 = sick leave or disability due to knee problems, to 10 = competitive sports (e.g., soccer, football, rugby) at national or elite level. For the current study, TAS was completed relative to present day activity level, as well as retrospectively for before knee injury.

The KOOS is a 42 item comprehensive measure designed for active individuals after knee injury.[116] It consists of five subscales: pain, other symptoms, function in daily living, function in sport and recreation, and knee-related quality of life. Each normalized subscale is scored separately out of 100, with higher scores indicating better function.

The ACL-RSI evaluates psychological readiness to RTS participation after ACLR in terms of emotions, confidence in performance, and risk appraisal.[118] It consists of 12 items (e.g. how confident are you that you can perform at your previous level of sports participation) each rated from 0 = 'not at all' to 10 = 'extremely.' An overall mean score is reported, with a higher score indicating greater psychological readiness to return to activity. It has high internal consistency (Cronbach's α =0.95) and high reproducibility (ICC=0.89).[133]

The MHLC-Form C is a condition-specific locus of control scale that focuses on health-related beliefs.[254] It examines the extent to which participants perceive their own behavior influences their personal health status (internal locus of control) or the degree to which their health is influenced by the actions of other people or due to fate, luck or chance (external locus of control). A study that included 588 patients diagnosed with one of four chronic conditions, including arthritis, established the 4-factor structure and determined the validity and reliability of scores in the four sub-scales: internal, chance, doctors, and others.[254] In the current study, questions were phrased specifically in relation to knee health.

4.2.1.2.1 Face and content validity

Both the face validity, the evidence to which the scores of a PROM look to be an adequate reflection of the construct to be measure,[105] and the content validity, the evidence to which the content of a PROM is an adequate reflection of the construct to be measured,[105] of the K-SES scale were determined based on the translation and cross-cultural adaptation process that involved extensive discussion and agreement by both the multidisciplinary committee and 10 participants who did the pre-testing 'think aloud' interviews.

4.2.1.2.2 Confirmatory factor analysis

Confirmatory Factor Analysis (CFA) was conducted to test and validate the a-priori hypothesis about the internal structure of the scale, including the number of proposed factors (two) and the relationship between these factors and items. It was hypothesized there will be two factors, with items 1-18 loading on the first factor (present knee self-efficacy) and items 19-22 loading on the second factor (future knee self-efficacy). Next the assumptions for CFA were evaluated. This included the examination of the correlation matrix to ensure enough inter-item correlation to proceed with CFA (i.e. that 20% of correlations >|0.30| thereby ensuring that the correlation matrix is not equal to an identity matrix) and detailed examination of each item's distribution [approximately normal distribution with skewness (absolute > 1=problem), and kurtosis (absolute > 7-9=problem)]. The remaining assumptions of all items being continuous with minimum 5-point Likert scale and adequate sample size were addressed in the study design.

Maximum likelihood estimation procedure was used and model fit was evaluated using the following a-priori indices: Root Mean Square Error of Approximation (RMSEA) lower bound <0.05 and upper bound 95% CI to be <0.10; Comparative Fit Index=0.95, Tucker Lewis Index=0.95; Standardized Root Mean Square should be close to 0.08. Modification indices were examined, only if necessary, to modify item loading and factor structure if hypothesis is to be rejected. All item coefficients and residuals were reported as well as the covariance between the factors.

4.2.1.2.3 Floor or ceiling effects

The presence of floor and ceiling effects as a reflection of content validity of the scale was examined. The percentage of respondents that score lowest (0) and highest (10) response category for each individual question on the K-SES was noted. Further, participants who score below 2 or greater than 9 in each K-SES subscale score, was noted. Floor and ceiling effect were considered to be present if greater than 15% score the lowest or highest possible scores.[255]

4.2.1.2.4 Internal consistency

Internal consistency is a measure of the interrelatedness among items on a scale.[105] Cronbach's alpha statistic, the percentage of test score variation attributable to true differences between subjects, was calculated for each of the two subscales ($K\text{-}SES_{present}$ and $K\text{-}SES_{future}$). As the K-SES is based on a reflective model, where all scale items are expected to be highly correlated and interchangeable,[256] a Cronbach's alpha between 0.7-0.95 was considered acceptable based on previous reccomendations.[255]

4.2.1.2.5 Construct validity

Construct validity refers to the extent to which scores on a PROM are consistent with theoretically derived hypotheses, with regards to its relationships with other instruments or differences between relevant sub-groups.[105] Eight pre-determined hypotheses were tested (Table 4.2). According to COSMIN guidelines, construct validity is considered good if >75% of these hypothesizes are confirmed.[255]

Table 4.2 Construct validity hypotheses of the English K-SES

	Hypotheses (in order of importance)
1	Participants who have returned to sport activities will score higher on the K-SES than participants who have not returned to sports activities.
2	Participants who have returned to their previous activity level will score higher on the K-SES than participants who have not returned to their previous activity level.
3	Participants who have had knee surgery in the last 6 months will score lower on the K-SES than participants who had knee surgery greater than 6 months ago.
4	Participants who scored high on the K-SES would also score high on the ACL-RSI.
5	There will be no correlation between the dimensions of the MHLC and the K-SES.
6	Participants who are satisfied with their knee function and activity level would score higher on the K-SES than participants who were not satisfied with their knee function and activity level.
7	There will be a correlation between scores on KOOS-QOL and KOOS-Sport subscales and K-SES.
8	There will be a correlation between the K-SES and participant's response to a single question from the KOOS Quality of Life subscale: "How much are you troubled by lack of confidence in your knee?"

K-SES: knee self-efficacy scale; ACL-RSI: Anterior cruciate ligament return to sport after injury scale; MHLC: multi-dimensional health locus of control scale; KOOS-QOL: Knee Injury and Osteoarthritis Outcome Score-Quality of Life subscale; KOOS-Sport: Knee Injury and Osteoarthritis Outcome Score-Sport and Recreation subscale

4.2.1.2.6 Reproducibility

For reliability testing, a sub-group of participants completed the K-SES on two separate occasions, 2-6 weeks apart. A sample size of 40-50 participants is aligned with previous recommendations for reproducibility testing.[255] This sub-group was minimum 6 months after injury or surgery to ensure minimal changes in K-SES score would be expected over this time frame. To further confirm this, they were also asked to repeat the KOOS and answer some brief questions about the stability of their knee function and new injuries over the last few weeks.

To examine relative test-retest reliability (stability over time), two-way random intraclass correlation coefficients for absolute agreement (ICC; 95% CI) were calculated (reliability increases as ICC approaches 1 and an ICC of > 0.70 is considered the minimum standard for reliability).[255] Absolute reliability was assessed using a Bland-Altman plot to calculate the mean

difference (MD), with 95% limits of agreement (LOA=MD$\pm$ 1.96 * SD_{diff}) between the first and second administrations of the K-SES. Absolute agreement is achieved when zero lies within the 95% CI for the mean difference, whereas if zero lies outside the 95% CI, a bias measurement is indicated.[257]

The measurement error, a measure of systematic and random error not related to a change in the measured construct, was represented by standard error of measurement (SEM= SD_1 x $\sqrt{}$ (1-r), where SD_1 is the standard deviation at baseline and r is the reliability coefficient from the ICC.) The smallest detectable change (SDC) is the lowest change that can be confidently considered for an individual (SDC_{ind}) or group (SDC_{group}) score beyond measurement error and was calculated following guidelines by Terwee et al (SDC_{ind}=1.96 x $\sqrt{}$2 x SEM; SDC_{group}= SDC_{ind}/ $\sqrt{}$n).[255]

4.2.1.3 Statistical analyses

Descriptive details about the sample were summarized as means and standard deviations or medians and ranges for continuous variables (as appropriate) and frequencies and percentages for categorical variables. All continuous variables were examined graphically for normality or tested using the Shapiro-Wilk normality test. The relationships between continuous variables were measured using Pearson or Spearman-rank correlation coefficient based on if normality assumptions were met. Correlations of <0.3 were considered low, between 0.3-0.49 were considered moderate; and >0.5 were considered high.[258] Independent sample T-tests or Mann-Whitney U test (as appropriate) with 95% CI were used to examine differences in K-SES scores between various sub-groups (return to sport versus not returned to sport; knee surgery <6

months versus knee surgery ≥6 months). The results presented are based on all available data. Statistics were performed using SAS (version 9.4).

4.3 Results

4.3.1 Translation, cross cultural adaptation, and face and content validity

Contact was made with R. Thomee, (original scale developer) who provided consent for the cross-cultural adaption, as well as rationale underlying the specific activities chosen for the questions in the original questionnaire (V1). While some activities included on the scale may not be common in this population (e.g. horseback riding), they were purposefully included to stimulate participant reflection on the potential demands of this activity for the knee, rather than participants immediately responding based on how the activity felt the last time it was done. The professional translator produced V2 based on the original Swedish K-SES. The primary difference between these versions was the use of the word *certain* in V1 and *confident* in V2. Discussion amongst the original scale developer, translator, and primary author resulted in the word *confident* being selected as most appropriate (V1-2). Back translations by two uninformed professional translators native to the Swedish language were very similar (VBT1, VBT2).

The multidisciplinary committee met via teleconference and reviewed all K-SES versions (V1, V2, V1-2, VBT1, VBT2). The content validity was assessed by making judgements about the comprehensiveness and relevance of all items, in relation to the construct of knee self-efficacy and to the patient population. Minor changes to improve phrasing and cultural clarity were made in consolidating all versions and creating the pre-testing version (V3). For example, the word

'forest' was replaced with 'woods' and 'making quick twisting movements with walking' was replaced with 'making quick changes of direction.'

Ten participants (7 male) who had sustained a variety of sport-related knee injuries in the past 5 years (ACLR: 4; fracture: 4; meniscus: 1; patellar dislocation: 1) agreed to participate in the pre-testing phase. Participants provided positive feedback on relevance of questions and phrasing in V3. Minor changes were made to section D to improve clarity and one question from section C was given a new sub-heading: '*how confident were you'* in performing strenuous exercise soon after injury or surgery) as participants' were confused if this referred to their past injury or a new injury. The face and content validity of the scale was considered acceptable after receiving input during pre-testing from individuals with previous knee injury and final approval from the expert multi-disciplinary committee. Subsequently, the measurement properties of this pre-final version of the English K-SES were evaluated.

4.3.2 Participants

Of the 152 participants who were screened and met the study inclusion criteria, 115 participated in the online data collection between October 2016 and August 2017 (response rate = 75.6%). The full K-SES was completed by 113 (98.3%) of participants. See Figure 4.1 for participant flow chart.

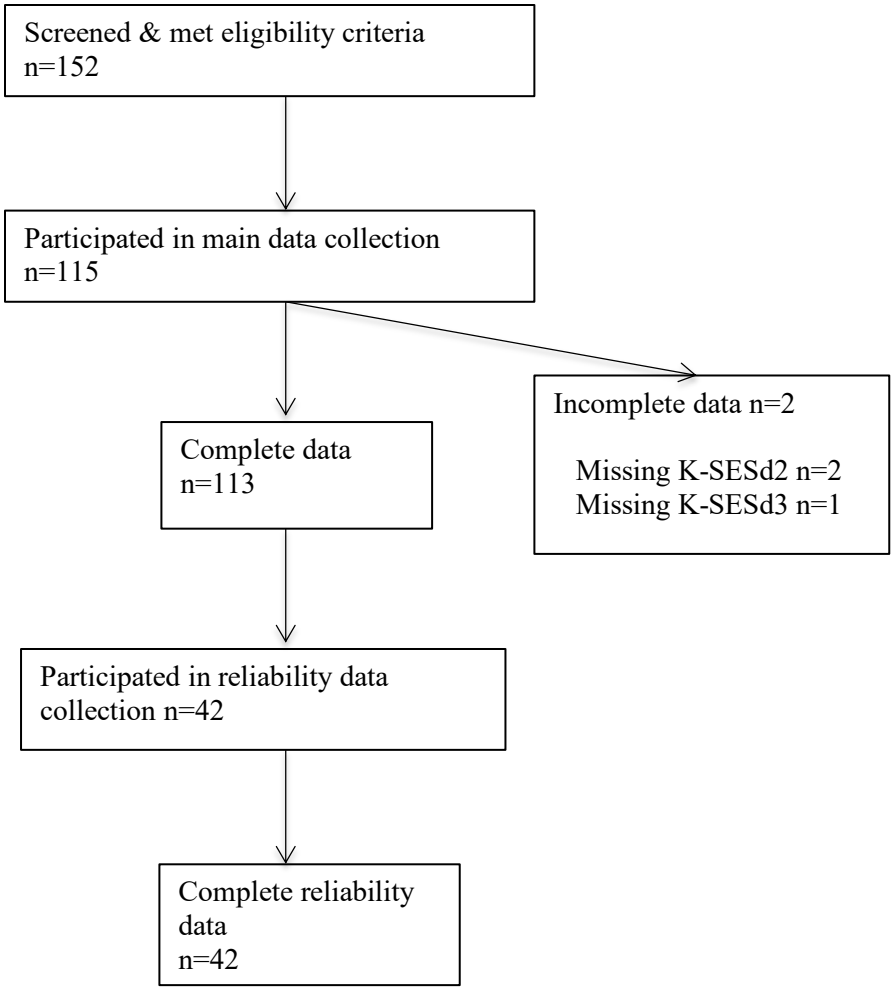


Figure 4.1 K-SES participant flow chart

Participants' median age was 26.9 years (range = 16.1-59.7). Median self-reported TAS was 4 and ranged from 0 to 10. Participants reported a median 1.5 years (range = 0.4-4.9) since their most recent intra-articular knee injury, which included injuries to the ACL most commonly (75.7%), followed by menisci (52.2%), and medial collateral ligament (26.1%). Just over forty percent of individuals stated they had RTS to some degree (40.9%), however over 2/3 stated their activity level was the lower than before the injury (70.4%). Further descriptive details about the sample are presented in Table 4.3.

Table 4.3 K-SES measurement properties evaluation: participant characteristics (n=115)

Variable	
Age, median (range) ð	26.9 (16.1-59.7)
Tegner, current median (range)	4 (0-10)
Tegner, before injury median (range)	9 (1-10)
Age initial injury, years median (range) ñ	23 (9-54)
Age most recent injury, years median (range)ø	25 (13-58)
Time since most recent injury, years, median (range) þ	1.5 (0.4-4.9)
Injured structures [n,(%)]	
ACL	87 (75.7)
PCL	5 (4.3)
LCL	7 (6.1)
MCL	30 (26.1)
Meniscus	60 (52.2)
Patella	9 (7.8)
Other	17 (14.8)
Surgery, yes [n,(%)]	74 (64.4)
Returned to sport, yes [n,(%)]	47 (40.9)
Level	
High performance	12 (25.5)
Regular	17 (36.2)
Participation	18 (38.3)
Activity Level [n,(%)]	
Lower than before injury	81 (70.4)
Same	20 (17.4)
Higher than before injury	14 (12.2)
Satisfied in knee function yes [n,(%)]	36 (31.3)
ACL-RSI, median (range)Ï	4.4 (0-10)
KOOS, median (range)ð	
Symptoms	71.4 (28.6-100)
Pain	83.3 (16.7-100))
Function, daily living	94.1 (20.6-100)
Function, sport and rec	60.0 (0-100)
Quality of life	43.8 (0-100)
MHLC, median (range)†	
Internal	27 (8-36)
Chance	14 (6-35)
Doc	12 (4-18)
Others	9 (3-17)

SD: standard deviation; ACL: anterior cruciate ligament; PCL: posterior cruciate ligament; LCL: lateral collateral ligament; MCL: medial collateral ligament; ACL-RSI: Anterior cruciate ligament return to sport after injury scale; KOOS: Knee Injury and Osteoarthritis Outcome Score; MHLC: multi-dimensional health locus of control scale

ð: n=112; ñ: n=114; ø :n=113; þ: n=110; Ï :n=107; †: n=106

4.3.3 Measurement properties

Before completing the factor analysis, two items were excluded from the K-SES: one item ("how confident were you in your ability to perform strenuous exercise soon after your injury or surgery") was excluded because the phrasing asked about past knee confidence and therefore was not relevant to either of the proposed factors (present or future knee-self efficacy). Another item ("how confident are you that your knee will not be worse than before surgery") was excluded as the English version was to be validated for a broader knee injury population (not solely post-surgical ACLR), for whom the question may not be relevant.

The original a-priori two-factor structure was evaluated using CFA, however it was rejected due to poor fit (Table 4.4) Based on modification indices and exploratory factor analysis, a three-factor structure was examined (*Present knee self-efficacy: movements and actions, Present knee self-efficacy: leisure activities and sports, and Future knee self-efficacy)* with one item [returning to pre-injury activity] removed since it failed to adequately load on either factor (revision 1). Then, two correlated error terms were added [Running after small children*Running after a streetcar/bus] and [Jumping sideways*Doing single leg hops] which greatly improved the fit (revision 2). In this solution (revision #2) there was a high correlation between the two *present knee self-efficacy* factors (r=0.93). A higher order factor was examined to improve the fit (revision #3), however while the fit indices were very similar to revision #2, it included a Heywood case (loading exceeded |1.0|). Given the modest sample size for conducting a CFA, this Heywood case likely reflects that the solution is too complex given the sample size. Therefore, the revision #2 is considered the final structure, and due to the high correlation between the two present factors, for the remainder of the analyses and dissertation they were

collapsed into one. Conceptually this is also aligned given the content in the items and the structure of the Swedish K-SES. The results for the factor analysis are shown in Table 4.5. The final English K-SES is in Appendix D.

Table 4.4 Model Fit Statistics

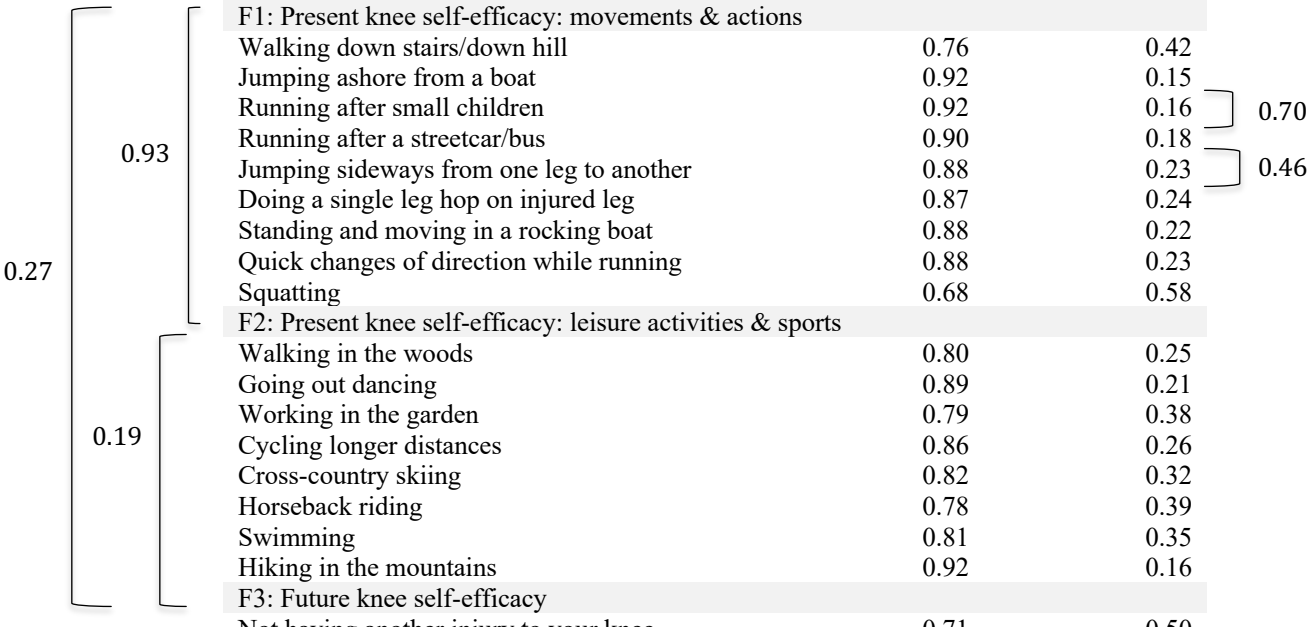
Model	X^2 (df), p-value	RMSEA (95%CI)	AIC BIC	CFI	SRMR
Hypothesized	X^2 (169)= 678.39, p<0.001	0.16 (0.15, 0.18)	9652.60 9764.06	0.80	0.074
Revision #1	X^2 (149)= 526.85. p<0.001	0.14 (0.13, 0.16)	9351.22 9326.27	0.85	0.060
Revision #2	X^2 (130)= 435.56 p<0.001	0.11 (0.09, 0.12)	9264.13 9238.35	0.90	0.052
Revision #3*	X^2 (146)= 346.42 p<0.001	0.11 (0.09, 0.12	9010.71 9130.72	0.92	0.053

RMSEA: Root mean square error of approximation; AIC: Akaike information criteria; BIC: Bayesian information criteria CFI: Comparative fit index; SRMR: Standardized root mean square

***Higher order solution: similar fit to Revision #2, however includes a "Heywood case" where loading for one of the parameters exceeded 1, likely due to a more complex solution with small sample.**

Table 4.5: Factor analysis results: Knee Self-Efficacy Scale

Items	Loading	Error variances
F1: Present knee self-efficacy: movements & actions		
Walking down stairs/down hill	0.76	0.42
Jumping ashore from a boat	0.92	0.15
Running after small children	0.92	0.16
Running after a streetcar/bus	0.90	0.18
Jumping sideways from one leg to another	0.88	0.23
Doing a single leg hop on injured leg	0.87	0.24
Standing and moving in a rocking boat	0.88	0.22
Quick changes of direction while running	0.88	0.23
Squatting	0.68	0.58
F2: Present knee self-efficacy: leisure activities & sports		
Walking in the woods	0.80	0.25
Going out dancing	0.89	0.21
Working in the garden	0.79	0.38
Cycling longer distances	0.86	0.26
Cross-country skiing	0.82	0.32
Horseback riding	0.78	0.39
Swimming	0.81	0.35
Hiking in the mountains	0.92	0.16
F3: Future knee self-efficacy		
Not having another injury to your knee	0.71	0.50
That you will not completely destroy your knee	0.81	0.35



Descriptive data on each of the K-SES subscales (present [factor 1 and 2] and future [factor 3]), are presented in Table 4.6. The present sub-scale had a median score of 6.47 (IQR=4.71) with a range from 0.18-10. The scores for this subscale were skewed to the left seen via observation of a histogram and the Shapiro-Wilk test ($p<0.001$). The future subscale had a median score of 6.75 (IQR=3.0) with a range from 0-10, with a similarly left skewed distribution [Shapiro-Wilk test ($p<0.004$)]. The distributional indices for each item are available in Appendix E. Between 0.88% and 29.57% of the answers for each item were 0 (floor effect), while between 7.08% and 46.00% of the answers were 10 (ceiling effect). For the present subscale, 10.43% of participants scored below 2 and 20.00% of participants scored above 9, whereas in future subscale 1.75% of participants scored below 2 and 8.70% of participants scored above 9. Internal consistency measured by the Cronbach's alpha statistic was $\alpha = 0.96$ for present knee self-efficacy and $\alpha = 0.73$ for future knee self-efficacy.

Table 4.6 Descriptive Statistics on K-SES scoring for 2 sub-scales (n=115)

	Subscale 1: present knee self-efficacy (17 items)	Subscale 2*: future knee self-efficacy (2 items)
Mean	6.17	6.43
(95% CI)	(5.65, 6.69)	(6.01, 6.83)
SD	2.86	2.26
SEM	0.27	0.21
Skewness	-0.49	-0.50
Kurtosis	-0.84	-0.31
Median	6.47	7.00
IQR	4.71	3.0
Minimum	0.18	0
Maximum	10	10

SD: standard deviation; SEM: standard error; IQR: interquartile range *n=113

Based on the factor structure, the construct validity hypotheses were evaluated for the K-SES present subscale scores. All eight a-priori hypothesis were confirmed (Tables 4.7 and 4.8). Participants who had RTS or their previous activity level scored higher on the K-SES present than individuals not RTS or previous activity level. Participants who had received knee surgery

in the last 6 months scored lower on the K-SES present than participants whose knee surgery was more than 6 months ago. Lastly, those who were satisfied with their knee function and activity level scored higher on the K-SES present than those who were unsatisfied. Positive correlations were seen between the K-SES present and each of the ACL-RSI, KOOS sport and quality of life subscales, as well as the individual KOOS knee confidence question. Each scale that correlated with the K-SES present shared between 14% and 56% common variance. As hypothesized, no correlation was found between the K-SES present and any of the MHLC dimensions.

Table 4.7 Construct validity hypotheses: K-SES scoring by various participant sub-groups

Sub-groups	Yes Median (range)	No Median (range)	Mean difference (95% CI)
Returned to sport activities	8.88 (2.24, 10.00) (n=47)	5.05 (0.18, 9.82) (n=68)	-3.22 (-4.12, -2.32)
Returned to previous activity level	8.85 (0.59, 10.00) (n=34)	5.59 (0.18, 9.82) (n=81)	-2.50 (-3.56, -1.43)
Knee surgery in the last 6 months	4.76 (0.18, 9.71) (n=37)	8.79 (2.82, 10.00) (n=36)	3.63 (2.58, 4.69)
Satisfied with their knee function and activity level	8.75 (0.35, 10.00) (n=36)	5.59 (0.18, 9.71) (n=79)	-2.54 (-3.58, -1.49)

CI: confidence interval

Table 4.8 Correlations between K-SES & other patient reported outcome measures

	r	r^2	*p*
ACL-RSI (n=107)	0.37	0.14	<0.0001
MHLC-Internal (n=106)	0.05	0.003	0.63
MHLC-Chance (n=106)	-0.02	<0.001	0.83
MHLC-Doctors (n=106)	-0.11	-0.012	0.25
MHLC-Others (n=106)	0.04	0.002	0.71
KOOS-Sport (n=112)	0.75	0.56	<0.001
KOOS-QOL (n=112)	0.65	0.42	<0.0001
KOOS-Confidence (n=112)	0.60	0.36	<0.0001

ACL-RSI: anterior cruciate ligament return to sport after injury scale; MHLC- Multi-dimensional Health Locus of Control; KOOS-Sport: Knee Injury and Osteoarthritis Outcome Score-Sport and Recreation subscale KOOS-QOL: Knee Injury and Osteoarthritis Outcome Score-Quality of Life subscale; KOOS-Confidence: Q3 from Knee Injury and Osteoarthritis Outcome Score-Quality of Life subscale

A sub-sample (n=42) completed the K-SES on two separate occasions (median 2.86 weeks apart, range = 2.00-6.86). Ten participants reported that their function had changed since the original data collection (improved=7; worsening=3), therefore these participants were removed from the reliability analysis (Table 4.10). To further confirm the participants' stability between the first and second administration of the K-SES, the ICC for each of the KOOS subscales were as follows: symptoms=0.77 (95% CI=0.62, 0.91); pain=0.90 (95% CI=0.83, 0.98); function in activities of daily living=0.89 (95% CI=0.81, 0.96); function in sport and recreation=0.85 (95% CI=0.76, 0.95), and knee related quality of life =0.89 (95% CI=0.81, 0.96).

In examination of test-retest reliability, the ICC for the present knee self-efficacy subscale was 0.91, while the future knee self-efficacy subscale was slightly lower at 0.74. No systematic change was seen between administrations with Bland Altman plots (Figure 4.2 & 4.3) revealing a mean difference between testing times of 0.085 and -0.44 for present and future knee self-

efficacy, respectively with 0 included within the 95% CI for both sub-scales. The SEM was below 1.5 points for both sub-scales, SDC_{ind} was 1.83 (present) and 3.58 (future), while the SDC_{group} were both below 1 (Table 4.9).

Table 4.9 K-SES scores, test-retest reliability, standard error of measurement, and smallest detectable change (n=32)

Subscale	K-SES Scores, median (IQR)							
	1st Assessment	2nd Assessment	Mean difference (95% CI)	95% LOA	ICC (95%CI)	SEM	SDC_{ind}	SDC_{group}
$K\text{-}SES_{present}$	8.71 (3.15)	7.85 (2.94)	0.085 (-0.24, 0.41)	-1.69 to 1.85	0.91 (0.85, 0.97)	0.66	1.83	0.32
$K\text{-}SES_{future}$	7.00 (3.50)	7.00 (3.00)	-0.44 (-1.03, 0.15)	-3.85 to 2.77	0.74 (0.57, 0.90)	1.28	3.58	0.63

K-SES: knee self-efficacy scale; $K\text{-}SES_{present}$: Present knee self-efficacy subscale; $K\text{-}SES_{future}$: Future knee self-efficacy subscale; IQR: interquartile range; ICC: intraclass correlation coefficient; SEM: standard error of measurement; SDC_{ind}: smallest detectable change at individual level; SDC_{group}: smallest detectable change at group level

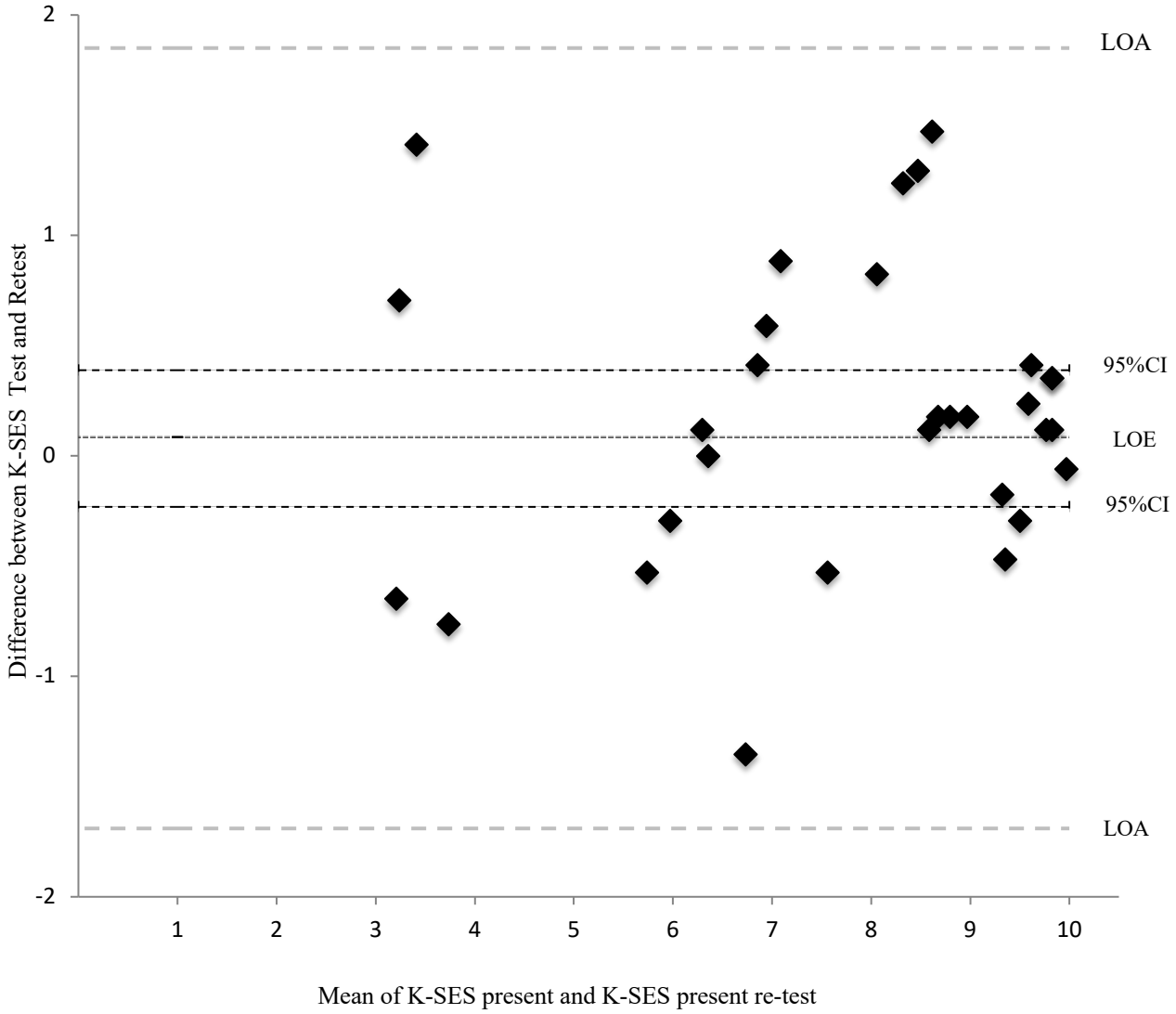


Figure 4.2 Bland Altman plot visualizing test-re-test reliability of the English K-SES present subscale
LOA: limits of agreement; 95%CI: 95% confidence interval: LOE: line of equity

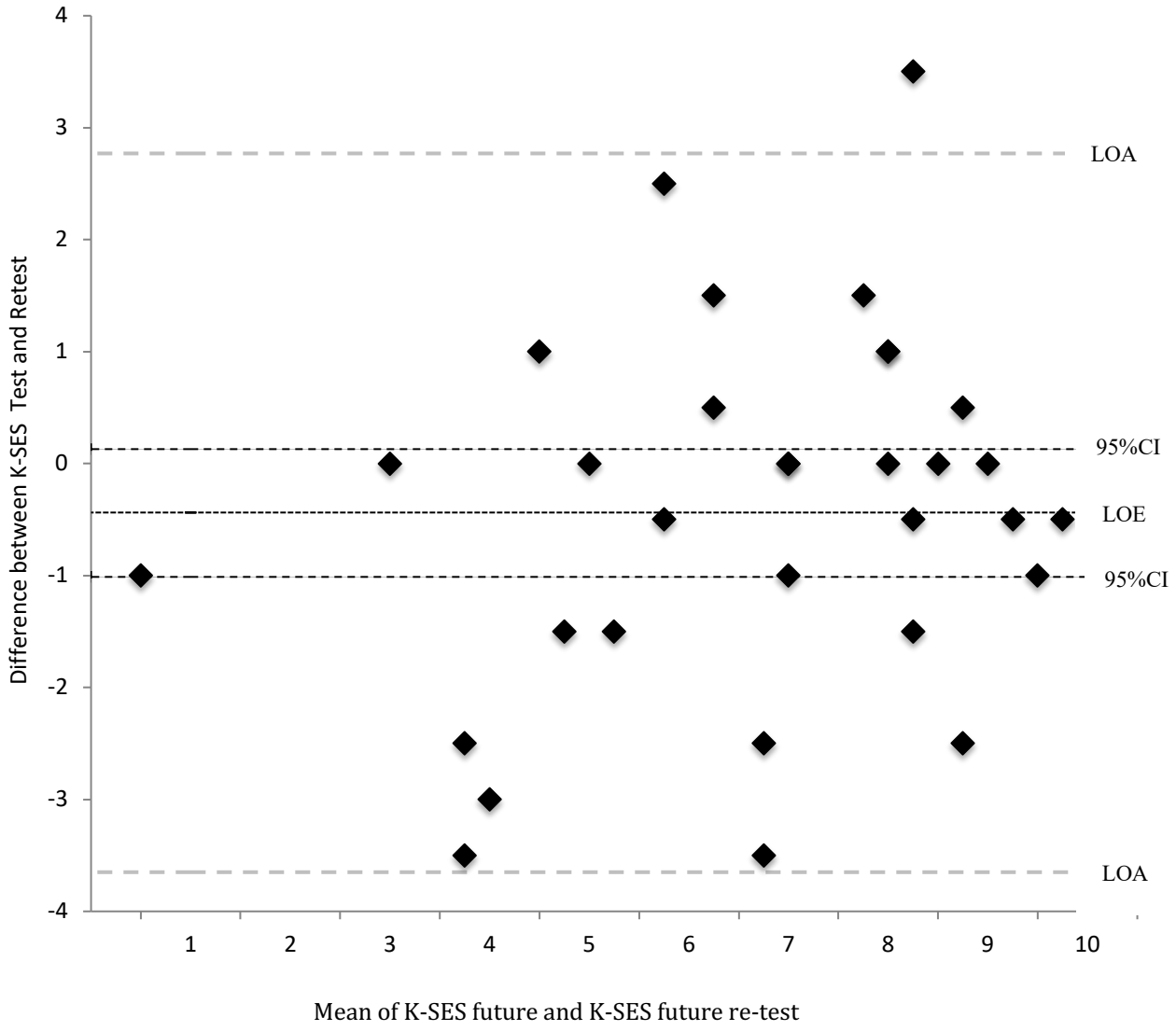


Figure 4.3 Bland Altman plot visualizing test-re-test reliability of the English K-SES future subscale
LOA: limits of agreement; 95%CI: 95% confidence interval; LOE: line of equity

4.4 Discussion

The results of this study illustrate that the K-SES has been preliminarily translated and cross-culturally adapted into English. The assessment of measurement properties was guided by a variety of COSMIN resources.[99,105,252] The English K-SES scores had high internal consistency, as well as acceptable construct validity and excellent reliability to measure knee-related self-efficacy in individuals aged 16-60 years old who have sustained a wide range of intra-articular knee injuries in the previous five years (Appendix D). Previously, higher knee-self efficacy was found to be related to self-reported PA and better longer-term health outcomes in Swedish studies involving participants with ACL rupture,[135,136] yet it requires further in-depth investigation in other samples. With this preliminary cross-cultural adaptation, K-SES scores should now be further validated in English speaking populations and with participants who have sustained a broader variety of knee injuries.

Overall, the results for the various measurement properties and the distributional indices for individual items on English K-SES were comparable to the original Swedish version.[120] For each scale item, participant responses were well distributed across response choices from 0-10. However, 16 items did have a ceiling effect. This may be indicative that knee self-efficacy is not a concern for everyone after a knee injury. Rather there may be a sub-group of individuals for whom it is problematic. Future studies may wish to investigate if there is a threshold level above which knee self-efficacy could be considered adequate. An alternative hypothesis is that very high knee self-efficacy may be concerning in its own right. If individuals are overly confident after a knee injury it may lead to reckless behaviours that could result in re-injury. Therefore, these individuals, nearly 15%, who scored > 9 on the overall scale, may also warrant further

evaluation and may need to be targeted with specific interventions such as education on re-injury risk. There was a floor effect seen in 5 items, which could have been due to the fact that we included participants who were only in a very acute stage of recovery after serious knee injury. Since previous studies have found knee self-efficacy to change during rehabilitation,[135] it could be that this scale is not appropriate for use in early phase of recovery.

Three items were removed from the English knee-self efficacy scale: two for content-related concerns and one due to the lack of fit in the factor analysis. Given the high internal consistency for the K-SES$_{present}$ sub-scale there may be some redundancy remaining among items,[255] however we did not choose to remove any further items, as the coefficient only just exceeded 0.95 and each item was believed to make a valuable contribution to the scale. In the original Swedish K-SES a Cronbach's alpha of 0.94 was reported for the full scale, and 0.78 for the K-SES$_{future}$ subscale, both very similar to the current study.[120]

The construct validity of the K-SES scores was demonstrated by confirming all eight a-priori hypotheses. As expected, those who had RTS or previous activity level had higher knee self-efficacy, than individuals who had not returned. Given the temporal ambiguity associated with a cross-sectional design, it remains unknown if higher knee-self efficacy encourages RTS, or if RTS contributes to having a higher knee self-efficacy. The lack of association found between the MHLC subscales and both the English K-SES (r= -0.11, 0.05) and Swedish K-SES (r=-0.18, 0.03)[120] illustrated divergent validity. Convergent validity was demonstrated with the moderate to high correlations between each of the KOOS-sport and KOOS-QOL subscales and the K-SES,

with each relationship shared close to 50% common variance. This is similar to the correlations reported between the Swedish K-SES and the KOOS subscales (r= 0.4-0.7).[120]

The high correlation between knee confidence and the K-SES emphasizes the similarities in these constructs. Knee confidence has been previously found to be a concern in youth and young adults with a history of knee injury (Chapter 3) and in individuals with osteoarthritis, where it has been found to be linked to greater fear of movement, increased knee pain with walking, and reduced muscle strength.[131,223] The K-SES has not yet been used to examine these associations.

The high test-retest reliability in the current study aligns with previous work (Swedish K-SES ICC=0.75)[120] and should be expected given the relative stability of the self-efficacy construct over a short duration. While our test-re-test interval was slightly longer than originally anticipated, it is reasonable to believe that any changes in a person's beliefs would still be marginally over this time frame. This stability was supported by the participants own self-rating of perceived improvement or worsening of knee function, as well as the high ICC associated with the repeated KOOS subscales.

The relatively low K-SES$_{present}$ SEM and SDC for both individuals and between groups suggest that this scale is able to detect true differences not attributable to measurement error between individuals with a change of 1.83 points on the 11-point scale, or between groups with a change of 0.32 points in mean scores with 95% confidence. The K-SES$_{future}$ had a higher SEM, and therefore also SDC, yet it is still reasonable to be able to detect a change at the group level of 0.63. These values align with another well utilized PROM that measure psychological constructs

related to knee injury and return to sport.[133] In the future, with further validation, the K-SES could be used as a PROM in a trial examining knee self-efficacy before and after an intervention.

Strengths of this study included the contributions of a multi-disciplinary committee and pre-testing participants in the cross-cultural adaption, as well as the use of COSMIN resources for assessment of measurement properties.[99,105,252] Further, the sample included a diverse variety of intra-articular knee injuries recruited from multiple sites. However, due to the study design, we were unable to evaluate responsiveness in this study. In the factor analysis, the sample size should be considered modest for this type of analysis and the RMSEA was slightly higher than ideal, however from a conceptual perspective this was the best fit for the model and the remaining fit indices were all within acceptable limits. Another limitation of this study is that while it is believed the K-SES is indeed measuring present and future knee self-efficacy, uncertainty remains without further validity evidence that can be derived in future studies. For example, the sub-scale K-SES$_{future}$ may be more accurately measuring long-term knee outcome expectations, rather than knee self-efficacy. A final limitation of the current study is the response rate of 75.6%. Unfortunately, we do not have any demographic or injury details about individuals who choose not to complete the online questions after screening. Yet, this response rate is similar to other studies evaluating measurement properties for knee-specific PROM.[133,250]

The psychological construct of knee self-efficacy should be further examined to understand the extent that it affects individuals after knee injury. If and how knee self-efficacy is related to RTS, PA, and longer-term joint health are important questions. There may be a sub-group of individuals whose behaviour is influenced by low knee self-efficacy. These individuals may

decide not to participate in sport or PA, thus having a detrimental impact on their long-term joint health. If this is found to be the case, neuromuscular training or psychological counseling interventions delivered after knee injury could target knee self-efficacy to promote engaging in healthy PA. The K-SES may be used as a PROM in a program that aims to achieve these goals. In this preliminary study, the English K-SES scores demonstrated acceptable validity evidence for evaluating the present and future knee self-efficacy in youth and adults who have had a previous intra-articular knee injury.

Chapter 5: **Physical activity participation, health-related outcomes, and recurrent injury in adolescent females following sport-related anterior cruciate ligament rupture**

5.1 Background

Participation in regular PA has been recognized as a key modifiable risk factor for the prevention of chronic disease, disability, and mortality worldwide.[185] In youth, PA is instrumental in stimulating cardiac health, bone and musculoskeletal development, as well as psychological well-being.[63,169] Adolescence and young adulthood is a particularly important time for engaging in positive behaviours such as PA that can be integrated into a lifelong healthy lifestyle.[171]

Sport participation is one of the primary sources of PA engagement for youth. However, sport-related injuries are the leading type of injury in this demographic[44] and evidence suggests injury rates are rising.[32] Traumatic musculoskeletal injuries are an important public health concern given their negative short- and long-term implications, such as pain, decreased function, social isolation, and reduced quality of life.[2,61,167]

The knee is among the most commonly injured joints during pivoting sports, with ACL rupture being one of the most devastating knee injuries for a young athlete.[23,24] In North America, ACLR is almost always advocated, which is followed by a lengthy progressive rehabilitation period.[32,90] The potential long-term consequences of ACL rupture include recurrent injury and PTOA,[1] a sub-type of OA. PTOA affects younger individuals who have a history of previous intra-articular knee injury and is characterized by chronic pain and disability.[86]

RTS is almost always cited as a key goal by injured athletes,[162] as well as considered a marker of successful injury recovery by clinicians and researchers.[114] However, just over half of athletes make a return to competitive sport one year after ACLR.[21] There is an abundance of literature examining physical and psychological factors that influence RTS after ACLR.[160,259] However, much less is known about the broader construct of PA participation, that includes the domains of active transport, occupational demands, and household activities, in addition to sport and recreation participation in this post-knee injury population.[190] Further, RTS or self-reported PA data are unable to provide objective measures of PA intensity and volume that would facilitate comparison with Canadian PA guidelines. These guidelines recommend 60 minutes per day of MVPA for children and adolescents aged 5-17 years of age and 150 minutes per week for adults 18 years and older.[182,183]

The development of self-identity is salient during late adolescence and is influenced by numerous social and cognitive factors.[260] Athletic identity, how strongly an individual identifies with the athlete role, can be a part of an individual's unified identity and can be influenced by various life experiences including sustaining a serious injury.[228,261] Athletic identity may influence an individual's depth of commitment to sport, and therefore the competitive level or types of sport with which they choose to engage.

Longitudinal tracking of leisure time PA from adolescence to young adulthood has found substantial variation and heterogeneity over time in the specific types of sport engagement.[262] Previous authors have suggested that opportunities available for participation in team sport are very different for 23-year olds compared to the high level of social structure and organization

that surrounds team sports for 13-year olds.[262,263] They argue that, realistically, PA in young adulthood does not involve continued engagement in the same sports that were common in adolescence.[263] Therefore, examining RTS in the years after ACLR may not provide an accurate or complete representation of PA participation in these youth and young adults.

Considering the high risk of recurrent injury in youth who choose to return to pivoting sports after ACLR, it may not be in their best interests to do so.[140,264] Rather, choosing to engage in other sports or forms of PA that would still result in the plethora of general health benefits,[63] as well as knee-specific benefits, such as maintaining muscle strength and improving function,[198] may be a more appropriate decision. Previous research has relied heavily on RTS as a key marker of successful recovery from ACLR.[114] If RTS is the only PA metric examined, the active individual who purposefully chooses to participate in different sports, either due to evolving athletic identity, changing sport opportunities, or due to their previous ACL rupture could be wrongly classified as having a poor outcome after ACLR.

The impact of previous injuries on PA participation has been examined in other populations and contexts. In Australia, adults who had sustained a serious sport or active recreational injury were found to have lower self-reported PA levels (compared to their pre-injury selves), independent of functional recovery, 12 months later.[194] In the US, college students with chronic ankle instability were found to have significantly decreased daily step count compared to healthy control students.[193] Also in the US, adults with a previous ACLR were found to spend less time in objectively measured MVPA than matched healthy individuals without a history of knee injury.[197] Taken together, it appears that individuals who have suffered a sport-related injury are

at risk of lower PA participation in the future, which is associated with numerous unfavourable health outcomes.

To the best of our knowledge, objectively measured PA has not previously been examined in female youth and young adults with a history of ACLR. Focusing on female youth is especially warranted for a number of reasons. First, female youth have lower overall objectively measured PA than their male counterparts, an average of 15 minutes less per day in youth aged 12-17 years.[19] Second, meta-analysis suggests that females have nearly double the incidence of ACL ruptures than males.[26] Third, females who have had ACLR have over significantly lower RTS rates than males who have had ACLR.[16,259] Fourth, females have significantly greater prevalence of knee OA than males.[79] Consequently, it is critical to develop an in-depth understanding of PA in female adolescents after ACLR and how it is related to other health-related outcomes and re-current injury.

5.1.1 Study objectives

The primary objective of this study was to determine if female youth and young adults who have had ACLR differ in objectively measured MVPA compared to healthy matched controls 1-2 years following reconstruction. The secondary objective was two-fold: 1) to determine how female adolescents who have had ACLR differ in other health-related outcomes compared to healthy matched controls; 2) to investigate the association between psychological factors and PA or RTS in girls who have had ACLR. There were also two exploratory objectives: 1) to explore the association between PA and RTS in those with previous ACLR; 2) to explore the association between previous injury, MVPA, or BMI with knee injury or recurrent injury within the

following 1 year.

5.2 Methods

5.2.1 Study design

This study was conducted with cohort of 102 female youth and young adults aged 14-22 years: 51 girls who had undergone ACLR in the previous 1-2 years (injury group) and 51 girls without a history of previous knee injury (control group), matched by age and previous sport background. Sample size was based on a-priori estimation of being able to detect a statistically significant difference in moderate and vigorous PA (5 min and 2.5 min per day, respectively) between injury and control groups and was based on pilot data from the University of Calgary (power=0.80; α=0.05).[106,265] Considering the mean minutes per day of moderate PA and vigorous PA in Canadian female young adults are 20 minutes and 4 minutes, respectively, this difference represents 25% and 63% of their daily PA and thus should be considered clinically meaningful.[179]

5.2.2 Ethics

Ethical approval for this study was given by the UBC Behavioural Research Ethics Board (H16-01938). At study entry, all participants provided written informed consent or assent accompanied by parental consent if under 16 years of age. As well, they completed a Physical Activity Readiness Questionniare (PAR-Q, 2002), a health screening tool, before participating in the physical testing portion of the data collection.

5.2.3 Participants

For the injury group, inclusion criteria at the time of recruitment included: 1) female; 2) aged 14-22 years; 3) received primary unilateral ACLR for a sport-related knee injury in the previous 1-2 years. Participants were excluded if they had undergone a previous ipsilateral or contralateral ACLR. For the control group, inclusion criteria included: 1) female; 2) aged 14-22 years; 3) reported no previous sport time-loss or medical consultations due to a knee injury. Each injury participant had a control participant matched by age (date of birth within 1 year) and previous sport (primary sport and competitive level). For both groups, exclusion criteria at the time of recruitment included: pregnancy; sustaining any musculoskeletal injury in the last three months that resulted in missed sport participation; inability to speak and understand English; or any systemic disease (e.g. cancer, heart abnormalities) or neurological disorder (e.g. head injury, cerebral palsy) that would preclude participation in any aspects of the data collection.

Participants with previous ACLR were recruited from 11 Orthopaedic Surgeons in the Greater Vancouver region, as well as through study information distributed by collaborators between September 2016 to October 2017. Potential participants were identified from surgical reports within their medical records by Medical Office Assistants (MOA) at their respective clinics and mailed an invitation letter. Within two weeks, MOA made follow up telephone calls to inquire if the letter was received and to confirm interest. To recruit the control participants, each injury girl was asked to suggest friend from her previous sports team at the time of knee injury. When this was not possible, a matched control participant was recruited through distribution of study information by collaborators and participants. Before inclusion, all participants were screened via telephone.

5.2.4 Main data collection

Following informed consent and study enrolment, available historical ACLR information from the time of surgery [e.g. age, time from injury, surgical details, concurrent procedures, anthropometrics (height, weight)] were obtained from participants' medical records (injury group only). A single in-person data collection session was conducted at 1 of 3 locations based on participant preference: North Shore Sports Medicine Clinic, North Vancouver, British Columbia (BC); Fortius Sport and Health, Burnaby, BC; or West Richmond Community Centre, Richmond, BC. Data collection consisted of completion of study specific questions [e.g. participant characteristics, injury details, PA participation, aspects of RTS] (Appendix L); anthropometric measurements [height (cm), weight (kg)]; patient reported outcome measures [TAS (Appendix I), KOOS (Appendix F), AIMS (Appendix M), K-SES (Appendix D), ACL-RSI (Appendix J), Tampa Scale of Kinesophobia (TSK-11) (Appendix N)]; functional tests (TSLH, OLR); and accelerometer instructions to obtain PA and sedentary behaviour outcomes.

5.2.4.1 Study specific questions

Participants completed a demographic and medical questionnaire that included questions about age, medical history, as well as past (pre-injury or 1-2 years ago) and present sport participation. For participants who had undergone ACLR, further details regarding mechanism of injury, rehabilitation details, and RTS were also obtained. RTS was evaluated by participants' responses to a series of questions developed based on international consensus to elict details regarding the extent and timing of their RTS.[16] In addition, questions probing reasons for not RTS and future plans for sport were included.

5.2.4.2 Anthropometric measurements

Anthropometric measurements were assessed using a medical scale (seca model 869, Germany) [weight to the nearest 0.1 kg] and stadiometer (seca model 217, Germany) [height to the nearest 0.1cm] to calculate BMI [(kg)/(m^2)]. BMI was examined as a continuous and categorical variable. For adolescents 14 to 19 years of age, BMI was converted into age and sex specific percentiles using US reference data and classified as follows: underweight (<5.0th percentile), healthy weight (5.0th-84.9th percentile), overweight (85th- 94.9th percentile), and obese (≥95th percentile).[266] Participants 20 years and older were classified based on accepted adult standards: underweight (BMI<18.5), healthy weight (BMI: 18.5-24.9), overweight (BMI: 25.0-29.9), and obese (BMI ≥30.0).[267]

5.2.4.3 Patient reported outcome measures

The TAS, a concise validated method to grade work and sport activities (0-10), was completed relevant to two time points: before ACL rupture (injury group) or 1-2 years ago (control group) and present day (both groups).[117,253]

The KOOS is a comprehensive measure designed for young active individuals after knee injury who are at risk of PTOA.[116] Through examination of the five subscales, KOOS was used to compare knee-related pain, symptoms, function in daily living, function in sport and recreation, and quality of life between groups. It has high test-retest reliability[268] and been validated in post ACLR and meniscectomy populations.[116,129] Each subscale is scored separately out of a possible 100, with higher scores indicating better function. Question three from the KOOS knee-related quality-of-life subscale, *"How much are you troubled by lack of confidence in your knee?"* was

used to assess knee confidence. Responses on the 5-point Likert scale were dichotomized into 'troubled' (mildly, moderately, severely, or extremely) or 'not at all troubled.' While not formerly validated, this question has been used to measure knee confidence previously.[131,132,223,231]

The AIMS was used to examine sport beliefs and the extent that participants' identified as an athlete in both groups.[269] Participants rated their agreement with 7 statements about affective, behavioural and cognitive aspects of athletic identity, from 1 (strongly disagree) to 7 (strongly agree). For example, one question asks: *I have many goals related to sport.* Answers were summed to obtain a final score, with higher scores indicating a higher athletic identity. The AIMS has been validated for use in adolescents and young adult populations.[132]

The K-SES[120] is a valid and reliable measure designed to gauge perceived self-efficacy of knee function in individuals after ACL rupture.[120] In the newly validated English version (chapter 4), participants respond to 19 items (0='not at all certain' to 10='very certain' about the task) from two sub-scales: $\text{K-SES}_{\text{present}}$ and $\text{K-SES}_{\text{future.}}$ The mean score from each subscale is reported with a higher score indicating greater knee self-efficacy. The English version has been found to have good test-retest reliability, high internal consistency, and acceptable construct validity with all nine a-priori hypotheses successfully confirmed in a knee injury population (see chapter 4 of this dissertation for further details).

The short form of the TSK-11[271] was used to evaluate fear of movement or re-injury in the injury group.[271] The TSK-11 eliminates the six psychometrically poor items from the original 17 item

version to create a shorter, yet still comparable measure with less participant burden.[271] Participants score each of the 11 items from 1=strongly disagree to 4=strongly agree, giving a final score between 11-44 points, with higher totals indicating a greater level of kinesiophobia. For example, one item states: *I'm afraid that I might injury myself if I exercise.* TSK-11 has been validated and used in ACLR populations.[272]

ACL-RSI was developed to evaluate psychological readiness to RTS after ACLR in terms of emotions, confidence in performance, and risk appraisal.[118] It consists of 12 items rated from 0= 'not at all' to 10 ='extremely.' One sample question asks: *are you confident that you can perform at your previous level of sport participation?* An overall mean score is reported with a higher score indicating greater psychological readiness to return to activity. It has been found to have high internal consistency (Cronbach's α =0.95) and high reproducibility (ICC=0.89).[133]

5.2.4.4 Functional tests

Each participant completed the TSLH[273] and OLR test.[274] The TSLH is a validated performance-based measure that assesses neuromuscular control, force generating ability, and leg confidence and has been used in an ACLR population.[106,275] Participants had one practice trial, then completed 2 trials of 3 consecutive single leg hops on each leg with the goal of maximizing horizontal distance covered.[111] A valid trial had a solid landing without twisting of the foot or touching down of the contralateral leg. The maximum distance for each leg was expressed as a percentage of leg length. The index leg of the participant in the injury group was compared to the same side leg of their matched control participant. The OLR test evaluates functional lower extremity strength and has been shown to predict development of knee OA in people aged 35-55

years old.[274] Participants began seated on a chair (0.48m) placing one foot on the ground, the other leg extended out in front, and arms relaxed at their sides. Using the single leg participants were instructed to rise to a standing position finishing with weightbearing knee in full knee extension, while maintaining the other leg straight forward and off the ground. One practice rise was allowed, then the number of rises completed while in full muscle control (i.e. no excessive trunk sway, arm use, or collapsing back to stool) was recorded for each leg. Up to a 5-minute rest between legs was given.

5.2.4.5 Accelerometer: physical activity outcomes

Participants were fitted with a triaxial Actigraph GT3X accelerometer (Actigraph, Pensacola, FL) on their right anterior superior illiac spine with an elastic belt at the level of the illac crest. Accelerometers are recognized as the gold standard for measuring PA in field settings[276] and have been used previously in young active populations.[197] The GT3X do not share any information with participants that could influence their PA. Participants were instructed to wear the device under clothing during all waking hours for the following 13 days obtaining a minimum of 10 hours of wear time per day.[180,277] To be included in multi-variable analyses participants needed to have a minimum of 4 valid days (minimum 10 hours of wear time), including 1 weekend day, as this was the same criteria applied in most recent Canadian population-based accelerometry studies of both adults and youth.[19,179]

A number of strategies were employed to promote accelerometer adherence. Participants received a logbook to record accelerometer wear time and non-wear time (i.e. swimming, bathing, or sleeping), to stimulate self-monitoring.[278] Clear written instructions, reminders, and a

tip sheet were included in the logboook. Participants had the option to receive automatic SMS text message reminders at individually specified times over the wear period, a strategy previously found to increase wear time in adolescents.[279] At the data collection session, an example of accelerometry data output was shown to participants, as another tactic to promote greater accountability.[278]

The Actigraph GT3X is pre-set to filter non-human motions with recording restricted from 0.25 to 2.5 hertz. Data were collected in raw acquisition mode, and subsequently processed and analyzed using ActiLife software, the proprietary software associated with Actigraph accelerometers. Monitor non-wear time and total wear time (TWT) were estimated and validated using reccommendations by Choi et al.[280] and the digitalized acceleration signal was converted into 1 minute epochs with an activity count for each epoch.

During data reduction, PA was classified into minutes of light, moderate, and vigorious PA based on validated cut points (light: 100-2019 counts; moderate: 2020-5998 counts; vigorous: $\geq$5999 counts).[180] A sensitivity analysis was conducted by repeating the primary analysis using validated youth cut points (light: 101-2295 counts; moderate: 2296-4011 counts; vigorous: $\geq$ 4012 counts) for participants who were under 18 years of age.[281,282] Previously, adult studies have counted only MVPA acumulated in at least 10 minute bouts, whereas youth studies counted all minutes of MVPA.[169] In the current study, it was decided to include all minutes of MVPA for numerous reasons. New 2018 American PA Guidelines propert that it is the total volume of MVPA that results in health benefits and that bouts of a prescribed duration are not essential.[184] For youth in particular, systematic reviews stress that all patterns of activity (sporatic, bouts, and

continuous) have been found to provide benefit.[169] Lastly, given this is the first study to examine MVPA using accelerometers in youth and young adults after knee injury, it was decided including all MVPA would result in a more inclusive understanding of PA.

PA outcomes obtained from the accelerometers included: mean minutes per day of light PA, moderate PA, vigorious PA, and MVPA. Meeting physical activity guidelines (PAG) [youth: 60 min/day of MVPA; adult: 150 min/week of MVPA] was examined and participants were dichotomized into yes or no groups, as appropriate. To calculate weekly PA, the mean min per day for each participant was multiplied by 7, to account for the varied number of valid number of days among participants.

5.2.5 Follow up data collection

One year following the main data collection, participants were emailed a link via Research Electronic Data Capture (REDCap), a secure, web-based application designed to support data capture for research studies that is hosted at BC Children's Hospital Research Institute.[283] Participants were asked if they had sustained any new or recurrent knee injuries within the past year, as well as their RTS status, and satisfaction with PA.

5.2.6 Statistical analyses

Descriptive statistics were summarized and reported as frequency (percentage) and mean (SD) or median (range), as appropriate based on data distribution, by group. Available historical participant characteristics were summarized for the injury group. All continuous variables were examined for normality (Shapiro-Wilk test) and homogeneity of variance when necessary. In the

case of missing data, the participant and their match were removed from that specific analyses. The median (range) and mean within-pair differences (95% CI) were calculated for the following outcomes: light PA, moderate PA, vigorous PA, MVPA, BMI (continuous), KOOS (5 subscales), AIMS, TSLH, and OLR. The minimally clinically important difference (MCID) for the KOOS was considered: pain=6; symptoms =5-8.5; function in daily living=7-8; function in sport= 5.8-12; knee related quality of life =7-7.2.[284] MCID have not been established for the remaining outcomes.

The assumptions for linear regression [Y values are independent; Y values are a linear function of X; homoscedasticity (constant variance); for a given x, y/errors are normally distributed] were evaluated and met through knowledge of study design and examination of residual plots and Q-Q plot. A multi-variable linear regression (95% CI) was done, accounting for clustering by pair, assessing the association of previous knee injury (exposure) with MVPA (outcome), including coefficients for age, TWT, time-since-injury (TSI), and BMI. The value for TSI for control participants was considered the same as their match, reflecting an equivalent knee injury-free time period. Regression analyses began with the full model. Using a backwards stepwise elimination approach, each variable was individually removed from the model to see its effect as a potential confounder between the primary exposure variable and the outcome. Collinearity was checked for all continuous variables. An interaction term between BMI and group (injury or control) was examined. The most parsimonious model was kept as the final model. As a sensitivity analysis, a multi-variable linear regression analysis between injury group and MVPA (with BMI as a covariate) was repeated including only participants (and their match) who had also sustained concurrent meniscus injury (n=24 matched pairs).

Using a similar model building strategy as described above, separate multivariable linear regression models, adjusted for clustering by pair, were used to assess the association between group (injury or control) and each of the following outcomes: BMI, AIMS, TSLH, and OLR, with covariates as appropriate (e.g. TWT, age). To adjust for multiple comparisons, a significance level of alpha = 0.01 was used (alpha=0.05/5). To examine the association between psychological factors (K-SES, ACL-RSI, AIMS, knee confidence and TSK-11) and MVPA or RTS multi-variable linear regression and logistic regression were conducted involving participants only from the injury group using the same backwards stepwise elimination approach. Before conducting the logistic regression, the following assumptions were considered: Y follows a binomial distribution; values of the outcome are independent; the expected value of y given x is given by the logistic function, and linearity between log (odds) and continuous variables.

For the exploratory objective, the association between MVPA and RTS (yes or no) using logistic regression was explored for participants in the injury group. As well, conditional logistic regression explored the association between new/recurrent knee injury or no knee injury (outcome) and each of group (injury or control), MVPA, and BMI, bi-variably. A multi-variable model was unable to be evaluated due to the relatively low number of 'events' in the outcome. All statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC).

5.3 Results

Participant recruitment is outlined in Figure 5.1. Participant characteristics at entry into the cohort are summarized by group (injury or control) in Table 5.1. Median age of participants was 17.8 years, varying from 14.6 to 22.6 years. In addition to ACL ruptures, 24 (47.1%) participants

in the injury group also sustained concurrent meniscal tears. Nearly 2/3 of ACL ruptures were described non-contact in nature. At the time of data collection, it had been median 1.7 years (range =1.1-7.3) and 1.1 years (range =1.0-2.0) since injury and surgery, respectively, for participants in the injury group.

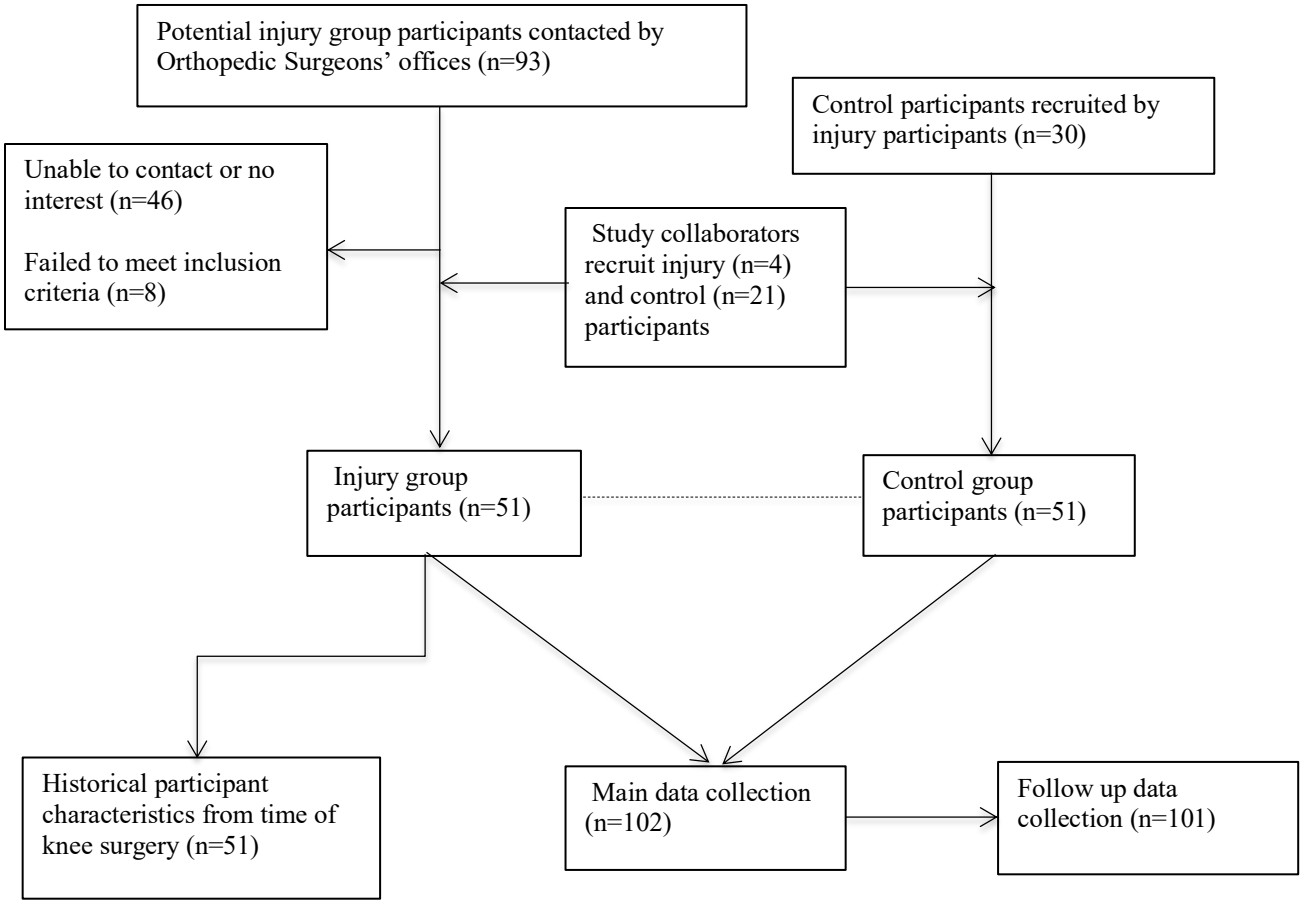


Figure 5.1 Participant recruitment and data collection

All participants in the injury group attended physiotherapy after their knee surgery, although the duration and number of treatments varied considerably. For participants in the injury group, 82.4% were troubled by knee confidence to some degree compared to 5.9% of individuals from

the control group. Notably, one in five girls from the injury group reported being either severely or extremely troubled by knee confidence.

Table 5.1 Participant characteristics at baseline recruitment into cohort (n=102)

Variable	Control n=51	Injury n=51
Age, yrs; med (range)	17.8 (14.6-22.1)	17.8 (14.9-22.6)
Height, cm; mean (SD)	165.1 (5.7)	166.0 (6.4)
Weight, kg; mean (SD)	61.6 (7.7)	64.0 (10.4)
BMI (kg/m^2); mean (SD)	22.6 (2.5)	23.3 (3.9)
BMI classification, n (%)		
Underweight	0	1(1.96)
Normal	43 (84.3)	39 (76.5)
Overweight	8 (15.7)	7 (13.7)
Obese	0	4 (7.8)
Injured structures; n (%)		
ACL	NA	51 (100.0)
MCL		2 (2.9)
Lateral meniscus		15 (29.4)
Medial meniscus		12 (23.5)
Mechanism of injury; n (%)$^{\beta}$	NA	
Non-contact		31 (63.3)
Contact		18 (36.7)
Previous knee injury, n (%)	NA	8 (15.7)
Patellofemoral pain		4 (50.0)
MCL		1 (12.5)
Meniscus		1 (12.5)
Other		2 (25.0)
Time since surgery yrs; med (range)	NA	1.1 (1.0-2.0)
Time since injury, yrs; med (range)	NA	1.7 (1.1-7.3)
PT		
Attended pre-surgery, yes; n (%)		45 (88.2)
Attended post-surgery, yes; n (%)		51(100.0)
Following surgery attended PT for; n, (%)		
<3 months		1 (2.7)
3 months		7(19.4)
6 months		6(16.2)
9 months		12(32.4)
12 months		10(27.0)
18 months		1(2.7)
Currently attending PT		14 (27.5)
Reasons for stopping PT; n, %		
Therapist discharged		12 (32.4)
Able to do exercises on own		10 (27.0)
Felt ready to stop PT		8 (21.6)
Interfered with school/work		2 (5.4)
Too expensive		2 (5.4)
Traveling		3 (8.1)
Number of PT sessions; med, (range)		57.5 (3-600)
Tegner Activity Scale,		
Pre-injury/1-2 years ago	9 (6-10)	9 (5-10)
Present	9 (2-10)	7 (1-10)

Variable	Control n=51	Injury n=51
Number of sports,		
Pre-injury/1-2 years ago	3 (1-12)	2 (1-9)
Present	2 (1-6)	2 (1-8)
RTS, yes; n (%)	NA	28 (54.9)
Performance level, n (%)		14 (50.0)
Time after surgery RTS, mths;		12.0 (3.5-22.0)
PAG, yes; n (%)[a]	31 (60.8%)	23 (46.0%)
Troubled by knee confidence, n %		
Not at all	48 (94.1)	9 (17.7)
Mildly	3 (5.9)	19 (37.3)
Moderately		12 (23.5)
Severely		6 (11.8)
Extremely		5 (9.8)
K-SES; med (range)		8.8 (3.4, 9.9)
ACL-RSI; med (range)		6.1 (1.3, 9.3)
TSK-11, med (range)		23 (12, 33)

yrs: years; med: median; cm: centimetres; kg: kilograms; BMI: body mass index; m: metres; ACL: anterior cruciate ligament; MCL: medial collateral ligament; PT: physiotherapy; mths: months; RTS: return to sport; PAG: physical activity guidelines; K-SES: knee self-efficacy scale; ACL-RSI: Anterior cruciate ligament return to sport after injury scale; TSK: Tampa Scale of Kinesiophobia
β: n=49; [a]=n=50 injury group

Available historical participant characteristics from the time of ACLR are presented in Table 5.2 for the injury group only. Median participant age at the time of surgery was 16.9 years (range 13.4-21.6) with a mean BMI of 21.7 (SD=3.2).

Table 5.2 Summary of available historical characteristics from time of ACLR (n=51)

Variable	
Age at surgery, yrs; med (range)	16.9 (13.4-21.6)
Time injury to surgery; mths, med (range)	5.4 (0.9-76)
Height at surgery, cm[Φ]	166.8 (6.4)
Weight at surgery, kg,[ϑ]	59.7 (9.0)
BMI at surgery (kg/m^2) [Φ]	21.7 (3.2)

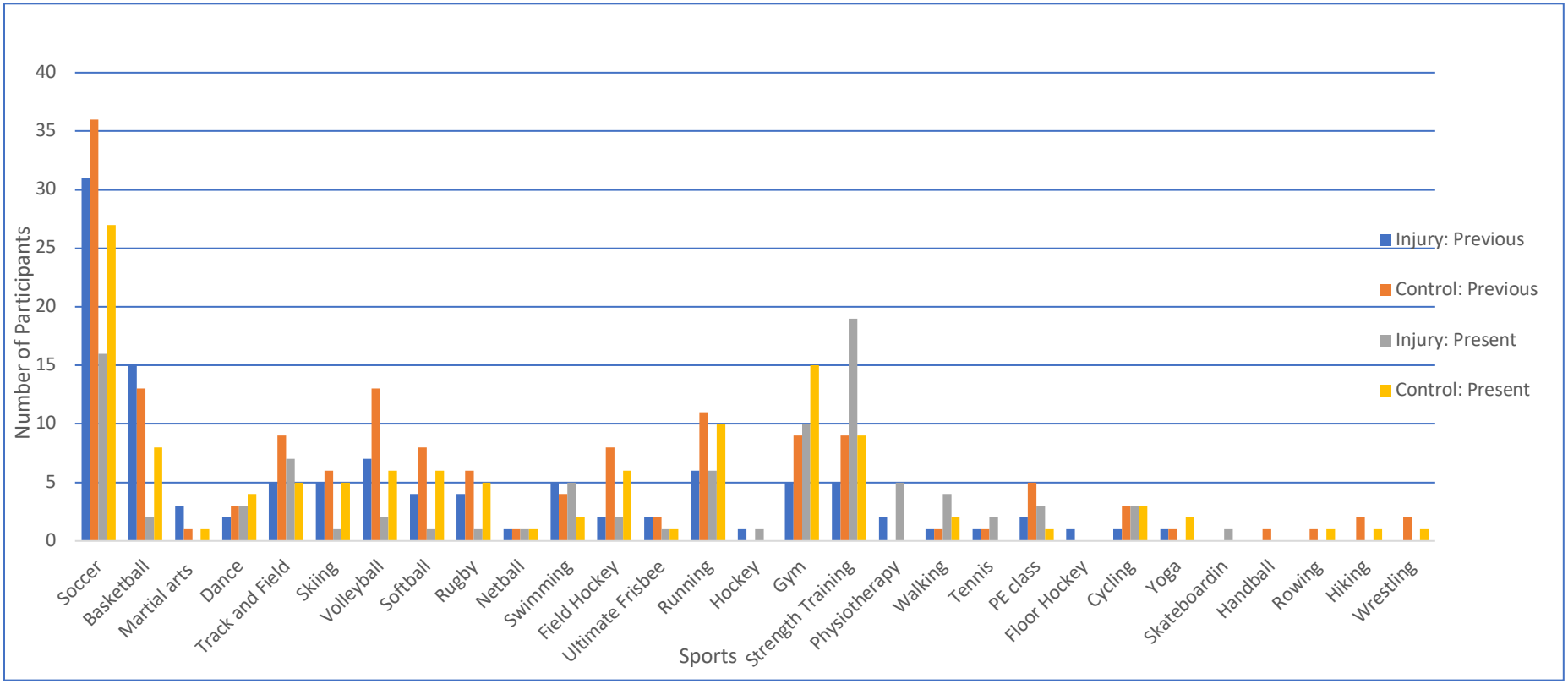
Values represent mean (SD) unless otherwise indicated
ACLR: anterior cruciate ligament reconstruction; yrs: years, med: median, mths: months, cm:centimetres; Kg: kilograms; BMI: body mass index; m: metres;
Φ: n=32; ϑ n=33

Participants reported previously (before ACL rupture/ 1-2 years ago) being engaged in a wide variety of sports for minimum 1 hour/week, with the most frequent being soccer, basketball, and volleyball (Figure 5.2). Present day sport participation had changed for both groups with a 48%

and 25% drop in the number of girls who played soccer in the injury and control groups, respectively. Among those in the injury group, 54.9% reported a different 'most important sport' from pre-injury, compared to 19.6% of girls from the control group. Further, more girls chose to engage in individual sports such as strength training (increased over 3-fold in injury group) and aerobic exercise at the gym (nearly doubled for control group). Figure 2 graphs all reported sports played at both time points (before ACL rupture/ 1-2 years ago and current day) by group.

One-to-two years ago, the median TAS score was 9 for both groups (ranging from 5-10); whereas current median TAS were 9 (range= 2-10) for the control group and 7 (range = 1-10) for the injury group. In the injury group, 55% of girls reported that they had RTS, and of these 50% stated that they had returned to the same performance level as before their knee injury and that this took median 12 months (range=3.5-22.0). Adult or youth PAG, as appropriate, were met by 60.8% and 46.0% of participants in the control group and injury group, respectively.

Figure 5.2 Participant sport details: all sports played previously [injury group: pre-injury; control group: 2 years ago] and present day



Descriptive details and mean within-pair differences for participants' PA, sedentary time, PROMs, and functional performance tests are given in Table 5.3. The mean matched-pair difference for mean/minutes per day of vigorous PA was significantly lower in the injury group [mean difference = -1.22; 95%CI= -2.40, -0.04], whereas no difference was found for the other PA intensities. Further, the injury participant had statistically significantly poorer KOOS scores on all five sub-scales, while meeting the MCID for lower KOOS scores on four sub-scales with the exception of activities of daily living subscale. Injury participants were also found to have significantly lower TSLH distance than control participants.

Table 5.3: Summary of physical activity, sedentary time, patient reported outcomes measures, and functional performance tests by study group and mean-within pair differences (n=102)

Outcome	Control median (range) n=51	Injury median (range) n=51	Matched pair difference[a] mean (95% CI) n=51 pairs
PA, mean min/day[b]			
MVPA	41.8 (11.6-158.7)	38.8 (8.1-108.9)	-6.40 (-15.95, 3.15)
Vigorous	2.6 (0-12.1)	1.1 (0-15)	-1.22 (-2.40, -0.04)*
Moderate	40.5 (11.6-153.6)	37.8 (7.9-105.6)	-5.17 (-14.11, 3.77)
Light	263.4 (122.9-381.7)	255.6 (110.8- 485.9)	8.16 (-15.83, 32.15)
KOOS			
Symptoms	96.4 (67.9, 100)	85.7 (32.1, 100)	-16.5 (-21.5, -11.5)*
Pain	100 (80.6, 100)	91.7 (66.7, 100)	-8.06 (-10.8, -5.3)*
ADL	100 (91.2, 100)	98.5 (82.4, 100)	-2.56 (-3.9, -1.3)*
Sport/rec	100 (80.0, 100)	85 (50.0, 100)	-15.69 (-19.6, -11.8)*
QoL	100 (68.8, 100)	62.5 (6.25, 93.8)	-35.17 (-41.7, -28.6)*
AIMS	40.0 (13.0, 49.0)	37.0 (15.0, 49.0)	-0.84 (-4.12, 2.44)
TSLH† (% leg length)	358.5 (268.8, 485.6)	333.75 (197.2, 511.2)	-38.0 (-61.5, -14.5)*
OLR†	40.0 (9, 213)	30.0 (6, 157)	-10.8 (-27.3, 5.7)

*95% CI does not include the null value of zero
[a] = values represent mean pair difference = injured – uninjured (95% CI)
[b]=values for participants with valid days (n=50 injury group; n=51 control group; n=50 matched-pairs)
† index leg (injury group) and matched leg (control group)
PA: physical activity; min: minute; MVPA: moderate and vigorous physical activity; PAG: physical activity guidelines; KOOS: knee injury and osteoarthritis outcome score; ADL: functions in activities of daily living; QoL: knee-related quality of life; AIMS: athletic identity measurement scale; TSLH: triple single leg hop; OLR: one leg rise

Among the 102 participants, 98 (96.1%) met the a-priori requirement of minimum four valid days (including one weekend day), resulting in 47 matched pairs to be included in the multi-variable analysis. For the primary objective, the results were consistent with the mean matched-pair difference, finding no significant association between group (injury or control) and mean minutes/day of MVPA, while controlling for BMI, TWT, TSI, and age (Table 5.4). The sensitivity analysis examining mean min/day of MVPA in the sub-group of injury participants who sustained concurrent ACL/meniscus injury (and their matched pair) was not significant [mean matched-pair difference = -8.10 (95% CI= -23.98, 7.78).] The results of the sensitivity analysis which repeated the primary objective with validated youth cut points for MVPA was essentially unchanged from the original analyses [coefficient for injury group: -4.40 (95% CI= -14.18, 5.38).]

For the secondary objectives, multi-variable examination of other health-related outcomes showed that the control group had a significantly better performance on the TSLH than the injury group, while controlling for TSI (Table 5.4). The other health outcomes (BMI, AIMS, and OLR) were not significantly different between groups.

Table 5.4 Associations between previous knee injury and MVPA and other health-related outcomes based on multivariable linear regression (n=51 matched pairs)

Outcome	Constant	Group[a] (control or injury)	BMI	TWT	TSI	Age
MVPA[β]	42.43 (-14.73, 99.21)	-4.14 (-14.35, 6.07)	0.12 (-1.52, 1.77)	0.001 (-0.015, 0.017)	-4.83 (-10.95, 1.29)	0.06 (-2.57, 2.69)
BMI	18.19 (12.44, 23.94)	0.62 (-0.63, 1.87)				0.28 (-0.034, 0.59)
AIMS	43.37 (28.22, 58.52)	-0.82 (-4.11, 2.47)			-0.79 (-2.32, 0.74)	-0.25 (-1.11, 0.61)
TSLH[b]	355.62 (329.63, 381.61)	-38.00* (-60.81, -15.19)			-13.57* (-23.78, -3.36)	
OLR	37.43 (15.52, 59.34)	-10.84 (-27.21, 5.53)			-6.34 (-13.71, 1.03)	

Values represent coefficient and 95%CI
*95%CI does not include zero
[a]Control group used as reference
[β]n=47 matched pairs
MVPA: moderate-vigorous physical activity; BMI: body mass index; TIS: time since injury; TSLH: triple single leg hop; OLR: one leg rise; TWT: total wear time; AIMS: athletic identity measurement scale
[b]index leg for injury group and matched leg (left or right) for control group

In examination of the psychological factors, the ACL-RSI scale and K-SES were found to be collinear ($r=0.67$; $p<0.001$). Given the K-SES had a stronger bivariable relationship with MVPA it was kept in the multi-variable model and the ACL-RSI was removed. The bivariable and multi-variable examination of an association between psychological factors (K-SES, TSK-11, AIMS, knee confidence) and MVPA in the injury group was not significant (Table 5.5).

Upon investigation of the same psychological factors and the odds of RTS, the ACL-RSI was found to have a significant bi-variable relationship with RTS, while the K-SES was not. Therefore, due to colinearity the K-SES was removed from the multi-variable model. In the final model, for every 1-point increase in AIMS score, there was a significant increase in the odds of RTS [1.16 (95%CI=1.03, 1.30)] (Table 5.6). In the bivariable models, a lower TSK-11 score, indicating less fear of injury, and higher ACL-RSI score, indicating greater readiness to RTS, were also associated with RTS, however these was no longer significant in the multivariable model.

Table 5.5 Associations between psychological factors and MVPA in injury group based on bivariable and multivariable linear regression (n=47)

Outcome	Constant	TSK-11	K-SES	ACL-RSI	AIMS	KC
MVPA	61.16 (-13.22, 135.54)	-0.44 (-2.07, 1.19)	-1.75 (-6.67, 3.17)	---	0.23 (-0.46, 0.92)	-11.94 (-29.31, 5.43)
MVPA	45.69 (15.09, 76.29)	-0.10 (-1.45, 1.25)				
MVPA	59.21 (25.93, 92.49)		-1.91 (-5.89, 2.07)			
MVPA	47.28 (33.23, 61.33)			-0.69 (-3.02, 1.64)		
MVPA	35.21 (9.69, 60.73)				1.55 (-3.10, 6.20)	
MVPA	45.75 (39.16, 52.34)					-13.22 (-29.17, 2.73)

Values represent coefficient and 95%CI

MVPA: moderate and vigorous physical activity; TSK-11: Tampa Scale of Kinesiophobia; K-SES: knee self-efficacy scale; ACL-RSI: Anterior cruciate ligament return to sport after injury scale; AIMS: athletic identity measurement scale; KC: knee confidence

Table 5.6 Bivariable and multivariable logistic regression examining the odds of return to sport associated with psychological factors in the injury group (n=50)

Variable	Unadjusted[§] OR (95% CI)	Adjusted OR (95% CI)
TSK-11	**0.81 (0.69, 0.95)***	0.93 (0.74, 1.18)
K-SES	1.34 (0.90, 1.98)	-
ACL-RSI	**1.71 (1.29, 2.28)***	1.37 (0.92, 2.04)
AIMS	**1.15 (1.06, 1.26)***	**1.16 (1.03, 1.30)***
KC	8.40 (0.96, 73.36)	5.64 (0.46, 68.99)

[§]Crude relationship between each variable and return to sport
*statistically significant
TSK-11: Tampa Scale of Kinesiophobia; K-SES: knee self-efficacy scale; ACL-RSI: Anterior cruciate ligament return to sport after injury scale; AIMS: athletic identity scale; KC: knee confidence

At mean 1.07 (SD=0.12) years, 101 (99.0%) participants completed the online follow up questions. Ten (19.6%) participants from the injury group had sustained a recurrent or new knee injury compared to 3 (6.0%) participants from the control group (Table 5.7). In the injury group, the majority of injuries were to the index knee (70%), involved the ACL and/or meniscus (70.0%), and were surgically managed (100%); whereas injuries to the control group participants involved the collateral ligaments or patella and were non-surgically managed (100%). For participants in the injury group, 66.7% stated they had RTS; however, of these, only 37.3% reported that they were performing at the level they were before their original ACL rupture. Of those who did not RTS (33.3%), the most common reason was due to changing interests or other commitments (58.8%). Across both groups, 60.4% of participants stated that they were either satisfied or very satisfied with their current PA participation, while 17.6% of the injury group and 12.0% of the control group said they were not satisfied to some degree.

Table 5.7 Participant characteristics at 1 year follow up (n=101)

Variable	Control n=50*	Injured n=51
Time since baseline, yrs; mean (SD)	1.07 (0.12)	1.08 (0.89)
New/recurrent knee injury, yes; n (%)	3 (6.0)	10 (19.6)
Injured side, ipsilateral; n (%)	NA	7(70.0)
Injured structures		
ACL	0	2 (20.0)
Meniscus	0	2 (20.0)
Concurrent ACL and meniscus	0	3 (30.0)
Other ligament	2 (66.7)	2 (20.0)
Patellar dislocation	1 (33.3)	1 (10.0)
RTS, yes; n (%)	NA	34 (66.7)
Performance level, n (%)		19 (37.3)
Reasons for not RTS; n, (%)		
Not given clearance by PT or surgeon		1(5.9)
Poor knee function or pain		1(5.9)
Chose other sports		1(5.9)
New interests or commitments		10 (58.8)
Other		4 (23.5)
Satisfied with PA participation$^{\beta}$		
Not at all	1 (2.0)	5 (10.0)
Not really	5 (10.0)	4 (8.0)
Undecided	11 (22.0)	13 (26.0)
Satisfied	24 (48.0)	19(38.0)
Very satisfied	9 (18.0)	9 (18.0)

*1 participant lost to follow up; yrs: years; SD: standard deviation; ACL: anterior cruciate ligament; RTS: return to sport; PA: physical activity; PT: physiotherapy; β: n=50 injury group

The small sample size and low number of 'events' resulted in wide confidence intervals for this exploratory analysis. Conditional logistic regression did not find significant odds of increased new or recurrent injury for any variable, however point estimates trended towards an association between both higher BMI and those in the injury group (compared to the control group) as having elevated odds of injury (Table 5.8). The odds of RTS (yes/no) associated with amount of MVPA was also non-significant [OR=1.00; 95% CI= (0.98, 1.03)].

Table 5.8 Conditional logistic regression examining the odds of sustaining a recurrent or new injury at 1 year follow up associated with group (injury or control), MVPA, or BMI (n=101)

Variable	Paired unadjusted OR (95% CI)
Injury Group	7.00 (0.86, 56.90)ó
MVPA	0.98 (0.93 1.03) †
BMI	1.24 (0.85, 1.82) ó

Control group is reference group; OR: odds ratio; 95% CI=95% confidence interval; MVPA: moderate and vigorous physical activity; BMI: body mass index
Ó: n=50 matched pairs; †: n=46 matched pairs

5.4 Discussion

This novel investigation aimed to examine PA and other health-related outcomes in female youth and young adults, a distinctive sub-set of the population that is at high risk of knee injury and consequently also at elevated risk of poor long-term health outcomes, including PTOA.

The unique study design that included age and previous-sport matched control participants facilitated a comparison of health outcomes with peers. The main finding of this study was that contrary to the original hypothesis, the primary objective did not find a significant difference in MVPA between female youth and young adults who had ACLR in the previous 1-2 years and healthy matched controls. However, other important findings provide evidence that at 1-2 years following ACLR these females have noteworthy health deficits including, on average, less vigorous PA participation; more self-reported knee pain and symptoms; lower self-reported knee function in sport; and reduced quality of life; and poorer neuromuscular control (measured by the TSLH) than their matched uninjured counterparts. Further, those with higher BMI at the main data collection, trended towards elevated odds of recurrent (or new) knee injury within the next year. Given that these female youth have already sustained a serious intra-articular knee injury and are at significantly increased risk of PTOA, the presence of increased adiposity, another modifiable PTOA risk factor,[154] is worrisome.

The main finding of the current study is in contrast to another recent investigation measuring objective MVPA in adults with previous ACLR, which found that these individuals had significantly less MVPA than their matched controls.[197] However, the amount of MVPA performed by these adults was substantially higher across both groups (injury: 78.34 mean min/day; control: 94.16 mean min/day) than the current study involving female youth and young adults (injury: 42.78 mean min/day; control: 49.17 mean min/day). Additionally, the previous study included adults up to 5.5 years since ACLR, a much longer time frame than the 1-2 years utilized in the current study. Conversely, another recent study involving youth and young adults 3-10 years after knee injury, failed to find a difference in self-reported PA between those with a previous knee injury and matched controls.[285]

Given the paucity of studies that objectively measured PA in this population, these results could be considered encouraging to clinicians and public health professionals by suggesting that female adolescents are remaining as physically active as their peers in the early years after ACLR. In fact, the amount of MVPA found per day in this cohort is comparable to the results from recent population-based Canadian children and youth accelerometry studies.[19] The CHMS (2014/15) reported that girls aged 12-17 years averaged 40 minutes (95%CI = 35-45min) of MVPA per day.[19] However, the CHMS data on Canadian female adults aged 20-39, reported slightly lower amounts of MVPA with an average of 24 minutes/day. [179]

An alternative explanation for these non-significant findings is that the sample size in the current study was not sufficient to be able to detect a significant difference in MVPA between groups due to the large variability in amount of PA amongst participants. Regardless, this study is the

first time objectively measured PA data have been gathered in this unique female post-ACLR population and should be considered stimulus for further in-depth study with larger sample sizes.

Importantly, the current study did find significantly lower minutes of vigorous PA for participants in the injury group compared to the control group. This is noteworthy considering that compared to lower intensities of PA, vigorous PA has been associated with better cardiometabolic markers (e.g. systolic blood pressure, fasting triglycerides, and insulin) in adolescents[286] and greater cardioprotective benefits in adults.[287] This is further supported by a systematic review that proports overall higher intensities of PA have more consistent and robust relationships with all health indicators in youth.[169] In the current study, the direction of the point estimate for mean-matched pair difference for light PA was reversed, meaning that those in the injury group trended towards higher amounts of light PA compared to the control group. It may be that injury participants were replacing vigorous PA with light PA.

The results of this study highlight the importance of distinguishing between the evaluation of RTS and the broader concept of PA participation. At the main data collection, just 54.9% and 27.5% of injury participants reported that they had RTS and returned to their previous performance level, respectively. These numbers are on par with previous systematic reviews that have summarized RTS at one year after ACLR.[21,160] Observed in isolation, these statistics suggest a dire situation for sport participation after ACLR. However, the objectively measured PA results in the current study, are in stark contrast to the negative RTS levels reported by participants and provide evidence that RTS and PA must be treated as separate constructs.

One of the advantages of accelerometers is their ability to capture PA data across domains including not just active recreation and sport, but also occupational activities, activities of daily living, and active transport, to facilitate a more complete and holistic perspective of PA.[190] Reinforcing this concept, the exploratory objective revealed that there was no difference in MVPA between participants who had RTS compared to those who had not RTS.

This study also highlighted that the psychological factors found to be associated with RTS should not be assumed to be related to PA participation. Previously, athletic identify was found to adapt after ACLR, hypothesized to decrease as a coping mechanism when the athlete role was threatened by difficulties during the rehabilitation processes.[228] In the current study, for every one unit increase in athletic identity the odds of RTS increased by 16%. This may not seem especially impressive, however a 5-point increase in athletic identity would have over doubled the odds (OR=2.10) of RTS and considering the variability in participant scores ranged from 13 to 49 points this is more meaningful. A screening test to quantify athletic identity in females following ACLR could allow clinicians to provide targeted guidance during rehabilitation. Female athletes with high athletic identity are likely more highly motivated to RTS, whereas females found to have lower athletic identity may need further intervention or could be guided towards other avenues for achieving healthy PA. Since none of the psychological factors examined in this study were found to be associated with MVPA, future studies should consider looking beyond intra-personal factors that influence PA to examine broader facilitators and barriers of PA such as environmental factors (e.g. access to recreational facilities) or social factors (e.g. peer support).[191]

The detailed descriptive data on sports played by participants in the current study suggests that many participants from both groups changed which sports they engaged in over the previous two years, with many shifting from team-based sports (e.g. soccer, basketball) to more individually-oriented sports (e.g. running, strength training). This behavior directly supports the theory that many youth and young adults change sports due to available sport opportunities and evolving interests.[263] Aligned with the current study, it has been found that PA that can be performed outside of structured context, such as jogging, cycling, and skiing, are more likely to be tracked from youth to adulthood.[262] An overemphasis on RTS, especially the same sport and at the same competitive level, may distract clinicians from encouraging overall healthy PA participation. This is even more critical to consider when a young individual is considering returning to a pivoting sport, where there is an increased risk of recurrent injury[264] such as meniscal or chondral damage, which could then accelerate development of PTOA.[70] In actuality, it may not always be in an individual's best long-term health interest to RTS.

Despite the positive findings regarding PA, the KOOS scores from the participants in the injury group suggest far from optimal health, with four of the five subscales meeting MCID for lower scores compared to the control group. The control groups' KOOS scores were similar to previous norms for young, active individuals.[130] If the injury group participants are suffering from pain and other knee symptoms, this could have negative influence on their PA in the years to come. The lowered quality of life found in the current study aligns with a previous systematic review that found reduced quality of life, measured by KOOS-QOL, in individuals greater than five years after ACLR compared to population norms.[138] Poorer quality of life was associated with

revision surgery, meniscal injury, and severe OA. Future studies are needed to investigate how these self-reported outcomes may influence behaviours such as PA in the coming years.

The exploratory objective found high incidence of knee injury or recurrent injury amongst all participants (incidence proportion: injury group=19.6%; control group=6%.) This aligns with previous meta-analysis suggest athletes younger than 25 who RTS have a secondary ACL injury rate of 23% and the majority of recurrent injuries have been found to occur during this early RTS phase.[140] The difference in type and severity of knee injuries between groups was interesting. No control participants sustained ACL ruptures and their knee injuries could be considered relatively minor compared to the injury group.

There are a number of strengths of the current study. Few studies have examined objectively measured PA after knee injury, with none specifically focusing on female youth and young adults at this critical time period of 1-2 years following reconstruction. Accelerometry measures all domains of PA and facilitates a more accurate and comprehensive understanding of PA than self-report PA, which is subject to reporting and recall bias. This study had exceptionally high accelerometer adherence; with an average of 15 hours daily wear time and 96.1% participants providing over 4 days of valid data. A great number of descriptive details were captured in this study, creating an in-depth appreciation of this specific subgroup. Height and weight were objectively measured to facilitate the most accurate BMI calculation. The high follow up rate of 99% is commendable and gives greater credence to the exploratory findings.

However, there are some important limitations to consider when interpreting the results from this study. The large variability seen in PA participation meant that the study may have been underpowered to detect a true difference in MVPA, however given the novel aspects of the study design and outcomes, this preliminary study provides a suitable foundation for future work. Further, despite best efforts to recruit an unbiased, representative sample of participants, those individuals who chose to participant may be higher functioning and more physically active than individuals who chose not to participate. However, selection bias was minimized by recruiting participants directly from multiple Orthopedic surgeon offices, rather than physiotherapy clinics. Measurement bias due to non-blinding of the assessor to study group (injury or control) may have occurred during the measurement of height and weight, as well as with the evaluation of functional tests. Knowledge of study group could unconsciously bias lower scores for those with a previous knee injury. Given the scope and resources available for this study as part of a doctoral dissertation, it was unfeasible to have blinded assessors. This potential bias was minimized by using a calibrated medical scale, as well as taking multiple measurements.

Although used widely in both research settings and clinical practice as a proxy for body composition, BMI does not discriminate between adiposity and lean mass and may inadvertently misclassify athletic individuals as overweight or obese.[288] However, the analyses in the current study used BMI as a continuous variable, rather than classifying individuals categorically and the results are aligned with previous work examining youth body composition by DXA and bioelectrical impedance after knee injury.[141,153] Ideally, a more valid and reliable measure of fat mass, such as DXA would be preferred, however it was beyond the scope of the current project. Injury participants in this study all sustained a ‘sport-related’ knee injury. Given the traumatic

forces that are required to rupture the ACL, the vast majority of these injuries occur in active, athletic youth and young adults during sport. Therefore, the results of this study are generalizable to females who typically present with this injury.

There are many external factors that could influence PA after ACLR in adolescent females. While this study focused largely on intrapersonal factors, future work may wish to consider how other broader influences such as school or work environment or social cultural environment (e.g. program availability, social norms) affect individuals with a history of previous ACLR. Lastly, the generalizability of study results should be limited to female youth and young adults following ACLR, and not considered representative of all individuals with previous knee injury. Importantly, female youth represent a distinctive sub-group that warrants this unique examination given their elevated risk of both knee injuries[26] and OA.[79]

5.4.1 Clinical implications

While the main results of this study could be viewed positively that female youth and young adults who have had ACLR appear to be attaining similar amounts of MVPA than their peers 1-2 years after surgery; they are doing so while reporting significant knee pain and symptoms, lower function in sport and recreations, reduced quality of life, as well as demonstrating lower neuromuscular control than those who have not had knee injuries. The discrepancy seen between reported RTS and PA participation highlight that clinicians need to expand conversations with patients beyond RTS to discuss goals, interests, and future plans for PA, especially for individuals who express less interest in RTS. Education should include promoting healthy PA to promote long term joint health. Also, clinicians should be cognizant of the high recurrent injury

risk in female youth and young adults at 2-3 years following surgery, as well as the potential association between increased adiposity and recurrent knee injury.

5.4.2 Conclusions

This study did not find a significant difference in MVPA between female youth and young adults in the 1-2 years following ACLR compared to their matched uninjured peers. However, they did have less vigorous PA, deficits across self-reported health outcomes including pain, symptoms, and quality of life, as well as reduced physical performance demonstrated on the TSLH. Psychological factors found to be associated with RTS were not associated with MVPA, reinforcing the important distinction between the two constructs. The results of this study should be interpreted with caution due to the small sample size and it should be considered a preliminary study to inspire further work in this area. Future research must consider examining a broader range of facilitators and barriers to PA in females following ACLR. PA should also be examined beyond the 1-2 year following reconstruction in this sub-group, especially given the presence of poor self-reported health outcomes that have the potential to negatively impact future PA participation if they are not specially addressed and improved.

Chapter 6: **Conclusion**

Sport-related knee injuries in youth and young adults are unfortunately a common and serious health concern, both from a personal perspective and due to the resulting public health burden. While extensive research has been conducted examining acute knee injury and best-practice rehabilitation, as well as the long-term implications of PTOA, there is a paucity of understanding surrounding the injured individual's experiences in the intermediate time period between these two phases. This dissertation sought to develop an in-depth understanding of the attitudes and beliefs about PA, physical and psychological health outcomes, and PA participation of youth and young adults in the early years following a knee injury. The primary hypothesis was that sustaining a knee injury would have a meaningful influence on PA beliefs, negative impacts on health outcomes, and would result in decreased PA participation in youth and young adults. Each chapter in this thesis aimed to generate new evidence to support this overarching aim and hypothesis. In this concluding chapter, the key findings of each study will be summarized. Following this, the results will be integrated into the larger clinical, public health, and research context. Lastly, future directions to advance this field will be discussed.

6.1 Study #1

In the first study (chapter 2), using a descriptive phenomenological approach, semi-structured qualitative interviews were conducted with youth and young adults who had sustained a previous intra-articular knee injury in the past 3-10 years to examine the influence of their injury on their attitudes and beliefs about PA and PTOA.

6.1.1 Key findings and contributions

This study revealed the following main themes and sub-themes:

(i) Acceptance: coming to terms with the impact of the knee injury

a. Current PA: while the knee injury had made a substantial impact on participation, participants had largely acknowledged this new reality.

b. Psychological aspects: participants noted the mental challenges associated with accepting the impact of the knee injury.

c. Current knee health: accepting the effects of the injury on their current knee health many years following the injury.

d. Beliefs about PTOA: understanding and accepting the possibility of future knee pain and symptoms.

(ii) Resiliency and determination: to recover from the knee injury

a. Learning experience: the knee injury experience came to be seen as an opportunity for personal growth with a large impact on adolescents.

b. Motivation: overall participants were highly driven and committed to recovery

c. Support: networks of family, friends, and physiotherapist played an important role in recovery.

(iii) Knee confidence: a significant problem after knee injury

a. Caution: there was a lack of trust in the knee that resulted in increased caution, and occasionally a fear of re-injury, when engaging in activities perceived to be high-risk.

b. Awareness: a sense of heightened consciousness surrounding the knee resulting in increased mindfulness of activities that may pose challenges.

c. Recovery and RTS: confidence influenced perspectives on recovery and decisions surrounding RTS.

(iv) Athletic identity: was evolving to influence choices

a. Sense of self as athlete: the degree to which participants related to the athlete role was diverse and varied.

b. Change in importance of sport: shifting of sport importance due to variety of factors including the knee injury, as well as other aspects of life.

c. New roles in sport: participants shifted to new sports and often adopted new roles within sport (e.g. coaching, refereeing.)

This qualitative study contributed a preliminary foundation of knowledge about PA beliefs in youth and young adults following knee injury and guided the direction of the remainder of the dissertation. It 'gave voice to participants'[289] focusing on the meaning and understanding of the experience to reveal their attitudes and beliefs about PA and PTOA. A strength of this study was that interviews were conducted with participants who had sustained a wide range of knee injuries, not solely ACLR, bolstering the transferability of the findings. However, the criteria for the broader PrE-OA study, which excluded anyone who had used non-steroidal anti-inflammatories in the previous 3 months, may have meant this was a higher functioning sub-group with better outcomes than the average person with a serious knee injury.

Importantly, the qualitative findings highlighted the lasting impact of the knee injury throughout the formative adolescent years, emphasizing the importance of psychological constructs such as knee confidence and athletic identity, beyond the physical consequences of injury. Most

participants viewed the knee injury as a complex multi-faceted experience, rather than exclusively a negative one, explaining how it was a learning experience that shaped whom they had become. Largely they had come to accept the injury's impact on their current PA and knee health. Unfortunately, many participants lacked understanding of PTOA and also felt that future knee pain was inevitable.

Comparatively to quantitative studies, there have been far fewer qualitative studies conducted with youth and young adults post-knee injury. Qualitative studies can help develop new ideas through induction, rather than by confirming or refuting hypotheses and improve the relevance of the outcomes to patients.[289] In the forthcoming clinical implications section of this conclusion, the findings of this study are integrated with the subsequent quantitative studies thus creating new, rich knowledge.

6.2 Study #2

In the second study (chapter 3), knee confidence was quantitatively examined in youth and young adults 3-10 years after sport-related intra-articular knee injury and compared to sex, age, and sport-matched controls without a history of previous knee injury, while controlling for body composition and PA. It was hypothesized that youth and young adults with a history of injury would have lower knee confidence than their uninjured peers. This lack of knee confidence may influence RTS decisions and PA choices that could have long term implications for joint health. Therefore, knee confidence may be a potentially modifiable risk factor for PTOA.

6.2.1 Key findings and contributions

This study contributed the following key findings to the field:

(i) Knee confidence was found to be a significant concern for many youth and young adults after knee injury, with nearly half reporting being troubled by lack of confidence to some degree.

(ii) Injury participants had significantly higher BMI, greater FMI, and lower KOOS scores indicative of impaired knee-related function than matched control participants.

(iii) After taking body composition and PA participation into account, those with a previous knee injury had over 7-fold increased odds of being bothered by knee confidence compared to the matched uninjured control participants.

(iv) No significant associations were seen between body composition or PA participation and knee confidence, respectively.

The main contribution of this study was that it was the first quantitative investigation of knee confidence in youth and young adults in the intermediate term following knee injury. Knee confidence has previously been examined in middle and older aged adults following ACLR,[223] as well as in individuals with knee OA.[131] Given the many troubling associations found between knee confidence and various health-related outcomes in these groups, such as lower quadriceps strength and self-reported increased pain with walking,[131,223] it was critical to examine if knee confidence was also a concern in a younger population at an earlier stage post-injury. This has revealed that knee confidence is a legitimate concern at numerous stages across the continuum

from post-knee injury to PTOA development although further prospective studies are required to determine the directionality of this association.

This was also the first study to explore the association between knee confidence and body composition or PA. There is strong evidence linking both increased adiposity and low levels of PA with joint health.[155,198] Given this, the potential of knee confidence to influence these two modifiable OA risk factors, could make knee confidence an important early treatment target.

A limitation of the current study was the self-report nature of the PA measure. Further studies are needed to examine knee confidence and objectively measured PA in different populations. Further, the influence of sex or time since injury on knee confidence was not examined in the current study. Lastly, the current study, as well as most of the previous studies examining knee confidence, have been cross-sectional in design. Ideally, knee confidence needs to be examined prospectively to prospectively see how it influences future behaviours like RTS and PA.

6.3 Study #3

The third study (chapter 4) of this thesis was a translation and cross-cultural adaptation of the K-SES, a PROM examining knee-specific self-efficacy, from Swedish to English in a sample of youth and adults with a history of a sport-related intra-articular knee injury in the previous five years. Secondarily, selected measurement properties of the English K-SES were evaluated to determine the validity and reliability of scores.

6.3.1 Key findings and contributions

The outputs from this study were as follows:

(i) Following COSMIN guidelines, a standardized multi-staged process that included input from professional translators, a multi-disciplinary expert committee, and pre-testing cognitive interviews with knee injury patients generated the pre-final version of the English K-SES.

(ii) The final English K-SES included 19 items in two sub-scales, present and future knee self-efficacy, based on the factor analyses.

(iii) Internal consistency, the inter-relatedness amongst items, for the two sub-scales was considered good.

(iv) All eight a-priori construct validity hypotheses that examined the relationships between the English K-SES and other PROMs, as well as differences in K-SES scores between patient sub-groups were confirming, demonstrating concurrent validity of scores.

(v) The test-retest reliability for the two subscales was excellent. This was demonstrated by both the relative reliability and the absolute reliability via Bland Altman plots which showed the mean difference between testing sessions included zero within the confidence intervals.

(vi) Measurement error, quantified through the SEM, was found to be adequate and comparable to other PROM. This resulted in reasonable SDC_{group} and $SDC_{individual}$ for being able to detect a change in patients after an intervention or over a given time frame.

The primary contribution of this study was to create an English version of the K-SES by translating and cross-culturally adapting the Swedish scale using standardized protocols[127] and expert recommendations.[99] The measurement properties of English K-SES were evaluated in a diverse sample of individuals with intra-articular knee injury in the previous five years. Validation is an ongoing process and this preliminary study created an English PROM that can be further tested to accumulate greater validity evidence. The results from the psychometric assessment illustrated that knee self-efficacy was a significant problem for many individuals following knee injury. While self-efficacy is recognized as a dynamic construct,[245] the utility of this scale in the acute or sub-acute phase of rehabilitation (e.g. <6 months after injury/surgery) may be questionable. The $K\text{-}SES_{present}$ subscale asks individuals how confident they feel about their ability to perform activities *right now.* A patient who is in the very early recovery stages from serious knee injury likely will NOT feel confident '*hopping on the injured leg'* or *'making quick changes in direction while running.'* Conversely, the same individual who is at end stage rehabilitation or considering RTS could have a very different answer. Further investigation is required to understand the most relevant time point to administer the K-SES, but this is likely closer to the end stages of recovery. An individual who scores low on the $K\text{-}SES_{present}$ at that point, may need to re-evaluate readiness to RTS, and may be in need of further physical or psychological intervention. Recent authors have suggested the necessity of including psychological evaluation as part of RTS criteria.[16,290]

The relationship between knee self-efficacy and recurrent injury is another important area that demands further investigation. An individual with low knee self-efficacy who engages in PA may exhibit timid or hesitant behaviour that may increase their risk of recurrent injury.

Conversely, consideration should be given to the potential problem of excessive knee self-efficacy and if this may be related to increased re-current injury. Given nearly one quarter of participants in the current study scored 9 or above for $K\text{-}SES_{present}$ this could indicate a reckless attitude and translate into risk-taking behaviours.

The $K\text{-}SES_{present}$ subscale was found to have a high correlation (r=0.60) with the KOOS-QOL question 3: *How much are you troubled by lack of confidence in your knee*, as was hypothesized in the construct validity hypotheses. However, this still resulted in only 36% of shared common variance between these two constructs of knee self-efficacy and knee confidence. Therefore, they should not be treated as synonymous and further research may be required to tease out the distinction between an individual's belief in the capabilities of their knee (knee self-efficacy) and an individual's confidence or trust in their knee.

One additional limitation should be noted for this psychometric study. The demographic details section failed to obtain participants' sex. This was an unfortunate oversight in the data collection and future research should consider the examining the potential influence of sex on knee self-efficacy.

6.4 Study #4

The fourth study (chapter 5) in this thesis aimed to comprehensively examine PA and other health-related outcomes in a cohort of female youth and young adults 1-2 years after ACLR compared to age-and-sport-matched controls without a previous knee injury. The primary objective was to determine if those who have had ACLR differed in objectively measured

MVPA compared to healthy matched controls. The hypothesis was that individuals with previous ACLR would have less MVPA than their matched peers. Secondary objectives were two-fold: 1) to determine if female youth and young adults who have had ACLR differ in BMI, athletic identity, TSLH, and OLR compared to healthy matched controls; 2) to investigate the association between psychological factors and RTS or PA in girls who have had ACLR. An exploratory objective was to explore the association between previous injury, MVPA, or BMI with knee injury or re-current injury within the following one year after the main study.

6.4.1 Key findings and contributions

This study made the following key contributions to the literature:

(i) Despite only just over half of participants reporting RTS, female youth and young adults with a previous ACLR did not have lower amount of MVPA compared to matched uninjured controls.

(ii) Participants with previous ACLR had less vigorous PA; self-reported clinically significant increased levels of knee pain and symptoms, and reduced function in sport and recreation, and knee-related quality of life; as well as poorer neuromuscular control than their uninjured counterparts.

(iii) None of the psychological factors (fear of re-injury, knee self-efficacy, psychological readiness for sport, knee confidence or athletic identity) were associated with MVPA in female youth and young adults with a previous ACLR.

(iv) Bi-variably, lower fear of re-injury, higher psychological readiness for sport, and higher athletic identity were associated with RTS in female youth and young

adults with a previous ACLR. Athletic identity was the only covariate that remained significant in the multi-variable model.

(v) There was a high rate of new or recurrent knee injury, nearly 1 in 5 girls from the injury group, within the following year.

(vi) Two-thirds of girls from the injury group had RTS by 2-3 years following ACLR. The most common reason given for not RTS was changing interests or other commitments.

(vii) Female adolescents with a higher BMI trended towards increased odds of sustaining a new or recurrent injury within the one year follow up.

The main novel contribution of this study to the literature was the high quality, objectively measured PA data that were obtained using accelerometers in female youth and young adults 1-2 years post-ACLR and the matched uninjured control group. Despite female youth being at exceptionally high risk of ACL injury[26] and vulnerable to low levels of PA participation,[19] compared to their male counterparts, PA has not been examined previously in this sub-group. Overall in this field, there is a paucity of studies examining PA (either self-reported or objectively measured) after ACLR compared to a far great number of studies that have focused more narrowly on RTS.

The emphasis on RTS may be partially motivated by injured athletes themselves who report very high expectations for RTS pre-surgery.[162,291] Yet, the reality is that far fewer individuals actually make a 'successful' RTS. For example, in a recent study examining patient expectations for RTS, 84% of individuals expected to RTS before ACLR, however 1 year later, 24% had actually

returned.[291] Leading experts in the field have recently argued that these estimates depend largely on how RTS is defined and quantified.[292] The current paper adopted a three-tiered RTS continuum for data collection, as has been recently recommended.[16] The findings regarding the proportion of participants who RTS in this current study are well-aligned with the most current review, giving face validity to some of the other novel findings.[293]

Another unique contribution of this study was the examination of both RTS and PA in the same participants. This highlighted the distinction between the two outcomes and how they should be treated as unique constructs in future studies. Given that none of the intra-personal factors in this study were associated with MVPA, this should motivate future studies to examine a broader range of external facilitating factors and barriers for PA including aspects of the physical and social environment.

Despite the positive results seen in the amount of daily MVPA in this female post-ACLR subgroup, it is important to recognize that secondary findings of this study revealed significant health concerns. One to two years following ACLR, females self-reported clinically significant levels of increased knee pain and symptoms; impaired function in sport and recreation participation; and reduced knee-quality of life. With these deficits, participating in PA may increase their risk of recurrent injury (e.g. if they have altered neuromuscular function and negative nervous system adaptations due to pain[294]) or cause further meniscal or chondral damage that could contribute to the development of PTOA.[70] Importantly, many of these female youth and young adults should not be considered 'back to normal.' This highlights the value of identifying modifiable risk factors for poor outcomes in individuals after ACLR and

implementing personalized management strategies to optimize longer term outcomes in females who have had ACL rupture.

A limitation of this study was the relatively small sample size. Examination of point estimates and confidence intervals showed that many variables were trending towards significance in the direction that was hypothesized. As part of the study design, matching was done for age and sport background, however this sample had a fairly narrow age range and were fairly homogeneous in sport background (both in volume and competitive level). Further these two matched variables did not have a strong relationship with the primary outcome of MVPA. Both of these factors resulted in the matching being less meaningful in the analysis than anticipated.

6.5 Integration of key results and implications

6.5.1 Physical activity participation

In this dissertation, PA was investigated using three distinctive approaches that allowed it to be evaluated from a variety of perspectives. Initially, the attitudes and beliefs about PA were explored qualitative via interviews in youth and young adults 3-10 years following knee injury. The theme of athletic identity was revealed, providing the direction for this dissertation to focus on PA rather than RTS, due to the participants' evolving perspectives and investment in sport.

Athletic identity was later examined quantitatively in chapter 5 (study 4) and found to be significant for greater odds of RTS, but not associated with MVPA. Based on the integration of the qualitative findings and the quantitative results, clinicians may wish to examine athletic identity in patients recovering from knee injury to help guide their rehabilitation goals for

targeted RTS or towards other PA opportunities. Physiotherapists and other health professionals may wish to emphasize the importance of sport and PA as an enjoyable lifelong pursuit, rather than focusing on returning to the previous competitive level of sport. For example, individuals with lower athletic identity may have different goals or expectations for their future PA, therefore ensuring they are introduced to a variety of options for healthy PA may result in high patient satisfaction and potentially better long-term joint outcomes.

From a public health perspective, the final phase of rehabilitation following a knee injury may be an ideal time to provide knowledge of health risks (e.g. re-current injury and PTOA) and to promote positive behavior changes (e.g. healthy PA participation without knee pain/symptoms) in young patients who would be at increased risk of recurrent knee injury should they choose to make an early RTS[104] or to sports that involve pivoting.[264] The social cognitive theory (SCT) is one behavior change theory that can be used to conceptualize considerations for promoting healthy PA (Figure 6.1).[295] It purports that knowledge of health risks and benefits creates the preconditions for change, but additional self-influences are necessary to overcome change barriers.[295] One of the primary constructs of the SCT is self-efficacy, the confidence one has in performing a health behaviour such as PA,[295] which has been discussed in the context of knee-specific self-efficacy in Chapter 4 (study 3) of this dissertation. A second construct is outcome expectations, one's judgements of the consequences that will occur as a result of performing or not performing the behaviour.[295] Central to the SCT is that people will behave in a manner that they believe will lead to positive and valued outcomes, while avoiding behaviours that they believe will result in an unfavourable outcome. If individuals understand the consequences of incomplete rehabilitation or early RTS, as well as the risks associated with pivoting sports (e.g.

re-current injury, PTOA) they may be motivated to make a gradual, safer RTS or different PA choices.

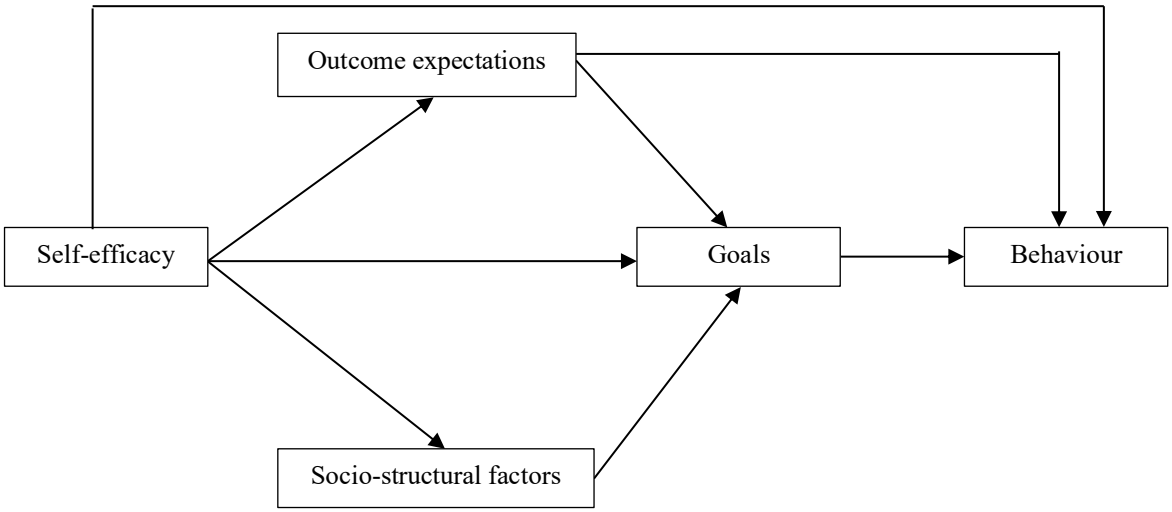


Figure 6.1 The social cognitive theory of health behaviour

Adapted from Health Education and Behavior, Volume 31, Bandura "Health promotion by social cognitive means", pp 143-164. 2004, with permission from Sage Publications.

Goals are another core construct of the SCT, which are purported to have a direct effect on behaviors as well as to mediate the influence of the other constructs in the model.[295] Importantly, goal attainment requires critical self-regulatory skills including self-monitoring, specific goal setting and self-reward. Lastly, socio-structural factors can act as a facilitator or barrier to behaviours; both indirectly through their influence on goals or by mediating the relationship between self-efficacy and behaviour.[295] In the current context, one example could be to build a positive social environment (e.g. group ACL rehabilitation) to aid individuals in reaching their goals and therefore also influence behaviour. A recent systematic review concluded that the SCT is a useful framework to explain PA behaviour and that self-efficacy and goals were consistently associated with increased PA.[296] Future research may wish to consider the development of a behavior change intervention using the framework of the SCT to inform individuals about health

outcomes after knee injury and to enable sustainable and healthy PA participation in this population.

A self-reported measure of PA, the modified GLTPQ was utilized in chapter 3 (study 2), which has significant limitations, as discussed earlier in this dissertation, including being vulnerable to recall bias, social desirability bias, and only capturing PA from the sport and recreation domain. However, the results of this self-report measure in study 2, mirror the results found with objectively measured PA in study 4. It may be that in the intermediate term after a knee injury, youth and young adults are indeed returning to a comparable PA level as their uninjured peers. However, the results of these studies show that they may be doing so with significant health deficits (e.g. self-reported increased knee pain and neuromuscular control deficits.) Importantly, future studies should continue to examine PA in this post-injury population longitudinally beyond this intermediate phase. Individuals who are engaging in PA with knee pain may be causing further joint damage that could results in earlier onset or more severe PTOA. If this is indeed the case, there may be a need to develop behavior change interventions to ensure individuals are maximizing their rehabilitation and early recovery after knee injury to help promote longer term joint health.

6.5.2 Knee confidence

Qualitatively, having a lack of knee confidence emerged as a key theme in first study (chapter 2), which led to its examination across all of the quantitative studies (chapter 3, 4, & 5) contained in this thesis. It should be acknowledged that inferences made based on this single question, should be tempered. Further investigation is required to determine if this question is actually assessing

knee confidence as has been assumed in this dissertation and by others in this field.[131,132,223] Overall, synthesis from this dissertation revealed that while knee confidence was not a concern for everyone after a serious knee injury, it was troublesome for a large proportion of youth and young adults. In this dissertation, it was not significantly associated with any health-related outcomes [PA (self-report or objectively measured), RTS, or BMI]. Yet, since it was found to be a problem for many individuals, across multiple study designs and methodologies, and showed some trending associations in the data, it warrants further study in the future.

In study 4 (chapter 5), those who were not troubled by knee confidence trended towards greater odds of RTS, which may indicate greater trust of their knee in sporting situation. It is possible that individuals who are bothered by lack of knee confidence are timid and make poor decisions in sport situations and that this could result in injury. This aligns with the experiences revealed in the qualitative data, where participants conveyed increased caution, lack of trust, fear of re-injury, and a heightened awareness of the knee during sport (chapter 2). Future studies may wish to evaluate if health professionals should to screen individuals for concerns about knee confidence before discharge from rehabilitation or beginning RTS. In a clinical setting, knee confidence could possibly be addressed through further physical rehabilitation (i.e. advanced neuromuscular training) or through psychological intervention (i.e. counseling).

In study 4 (chapter 5), those who were not bothered by knee confidence trended towards less MVPA. This seems contrary to the hypotheses in study 2 (chapter 3). However, it is possible that individuals who are bothered by knee confidence are not engaging in as much 'risky' PA or 'testing' their knee, in comparison to individuals who are more physically active. Thus, these

more active individuals are more aware of confidence concerns. Due to the cross-sectional nature of the data collection for this dissertation, the temporality of these relationships between knee confidence and RTS or PA is unknown. This highlights the necessity for future prospective studies examining knee confidence, as a potentially modifiable factor, that could influence the longer-term health outcomes for youth and young adults after knee injury.

The results in Chapter 4 (study 3) and chapter 5 (study 4), proport that knee confidence and knee self-efficacy are unique constructs. While they did share some common variance and trend in similar directions in multiple analyses, it is recommended that future studies continue to examine both constructs independently and their potential associations with health-related outcomes for youth and young adults after knee injury. As Alberta Bandura noted: "Confidence is a nonspecific term that refers to strength of belief, but does not necessarily specify what the certainty is about… Perceived self-efficacy refers to belief in one's [specific] capabilities."[297] Further research should further examine the construct of knee self-efficacy within the larger context of the other SCT variables (i.e. goals, outcome expectations, socio-cultural factors).

6.6 Public health perspectives

As discussed at the beginning of this dissertation, knee OA is a debilitating, chronic disease, with rising prevalence,[84] and is associated with personal suffering for individuals and high financial costs for society.[80,85] For example, in the United States, total joint replacements (TJR) of the knee, the gold standard treatment for severe disease, were estimated to cost $28.5 billion annually in hospital expenditures.[298] The increasing rates of youth knee injury,[26,32] combined with high levels of obesity,[299] and global endemic of physical inactivity,[185] could result in

massive increases in the number of TJR surgeries required in the future. Understanding how best to maximize health-related outcomes after knee injury in order to prevent a downwards health sequelae will be essential for minimizing public health burden.

Compared to idiopathic OA, PTOA impacts individuals at a younger age, during prime income earning years, resulting high job-related OA costs and indirect costs due to loss of productivity for society.[300] Further, knee pain and physical impairment can hamper leisure and social roles, meaning that these individuals with PTOA are less likely to engage in PA, including exercise and activities of daily living.[301] This can lead to further deconditioning, worsening disability, and the development of co-morbidities (e.g. heart disease, metabolic syndrome).[302] Evidence has found that in early knee OA, diagnosed in individuals aged 45-65 years, over 2/3 of people have at least one co-morbidity.[303]

Ideally, much of the personal and societal burden of PTOA could be prevented, through primary prevention of sport and occupational injuries,[1,304] or through secondary prevention and early intervention strategies.[302] From a population health perspective, this should focus on minimizing the effect of modifiable risk factors including adiposity, muscle weakness, physical inactivity, and lifestyle choices.[305] Undoubtedly, the greatest potential for alleviating PTOA would be to direct research and clinical resources towards an up-stream approach with evidence-based early interventions.[304,306]

6.7 Future directions

Undoubtedly, this dissertation provides stimulus for additional research in this area. Further qualitative studies would allow greater in-depth exploration of the transition back to PA after knee injury including an individuals' process for RTS or rationale for changing sports; facilitating factors and barriers to PA; and insight into how best to encourage healthy PA that aligns with their individual goals, values, and priorities. Knee self-efficacy could be further examined in individuals at the end stages of rehabilitation, when individuals are transitioning back to PA. Then in the following years, its potential influence on PA behaviours could be prospectively monitored, along with other knee-related health outcomes.

The poor self-reported health outcomes found in the cohort of female youth and young adults at 1-2 years following ACLR are especially troubling and the ongoing influence of these outcomes beyond 2 years on sport and PA are unknown, thus future larger, prospective studies are warranted. Future studies should consider further examination of objective PA in a broader post-knee injury population that includes both men and women to allow greater generalizability and to facilitate comparison between genders. Lastly, future researchers are encouraged to look beyond the intrapersonal factors that influence health behaviour to the broader range of extra-personal factors that could be impacting PA such as social, environmental, or policy factors.

6.8 Conclusions

The studies in this dissertation have made a valuable contribution to what is known about the intermediate period after recovery from acute knee injury, but before the traditional onset of PTOA. Qualitatively, new themes emerged as potential avenues for further investigation. Many

youth and young adults were found to be troubled by knee confidence, although the implication for this in the longer term are unknown. The English Knee Self-Efficacy Scale was translated and cross-culturally adapted from Swedish. It now warrants further testing and scrutiny in English speaking populations with previous knee injury. Lastly, this dissertation found that in the intermediate term, female youth and young adults are staying physically active after knee injury, yet this is despite other significant health deficits. Overall, this dissertation provides justification that that longer-term studies are needed to truly understand the long term the impact of sport-related youth knee injury on various aspects of health.

The findings in female youth and young adults in particular provides strong rationale that further prospective, longitudinal studies should be prioritized to understand what happens to this high-risk PTOA subgroup over time with regard to their PA participation and joint health. This research direction focusing on 'Pre-OA' or early OA disease stages and the role of potential risk factors (i.e. injury, adiposity) for disease progression is aligned with research priorities identified by European League Against Rheumatism (EULAR).[307]

This dissertation also highlighted the discrepancy between the outcomes of RTS and PA. It is recommended that future work examine the broader construct of PA and to look beyond intra-personal factors to examine how broader influences, such as school environment or social cultural environment (e.g. program availability, social norms)s[189,190] affect individuals with a history of previous ACLR.

The closing message from this dissertation is that in the years following an intra-articular knee injury, youth and young adults are not fully recovered. Whether they have physical limitations or psychological concerns the results of this dissertation stress the importance of further improving rehabilitation after knee injury and continuing to monitor and intervene in order to improve the health of this high-risk PTOA subgroup as they move into middle adulthood.

References

1. Caine DJ, Golightly YM. Osteoarthritis as an outcome of paediatric sport: an epidemiological perspective. Br J Sports Med. 2011;45(4):298–303.
2. Louw QA, Manilall J, Grimmer KA. Epidemiology of knee injuries among adolescents: A systematic review. Br J Sport Med. 2008;42(1):2–10.
3. Maffulli N, Longo UG, Gougoulias N, Loppini M, Denaro V. Long-term health outcomes of youth sport injuries. Br J Sport Med. 2010;44:21–5.
4. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequences of anterior cruciate ligament and meniscus injuries. Am J Sport Med. 2007;35(10):1756–69.
5. Janssen I, Leblanc A. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. Sch Nutr Act. 2015;183–219.
6. Lear SA, Hu W, Rangarajan S, Gasevic D, Leong D, Iqbal R, et al. The effect of physical activity on mortality and cardiovascular disease in 130 000 people from 17 high-income, middle-income, and low-income countries: the PURE study. Lancet. 2017;390(10113):2643–54.
7. Sothern MS, Loftin M, Suskind RM, Udall JN, Blecker U. The health benefits of physical activity in children and adolescents: Implications for chronic disease prevention. Eur J Pediatr. 1999;158(4):271–4.
8. Van Melick N, Van Cingel RE, Brooijmans F, Neeter C, Van Tienen T, Hullegie W, et al. Evidence-based clinical practice update: Practice guidelines for anterior cruciate ligament rehabilitation based on a systematic review and multidisciplinary consensus. Br J Sports Med. 2016;50(24):1506–15.
9. Kruse M. Exercise rehabilitation after anterior cruciate ligament reconstruction. J Bone Jt

Surg Am. 2012;94:1737–48.

10. Hochberg MC, Altman RD, April KT, Benkhalti M, Guyatt G, McGowan J, et al. American College of Rheumatology 2012 recommendations for the use of non-pharmological and pharmological therapies in osteoarthritis of the hand, hip, and knee. Arthritis Care Res. 2012;64(4):465–74.
11. McAlindon TE, Bannuru RR, Sullivan MC, Arden NK, Berenbaum F, Bierma-Zeinstra SM, et al. OARSI guidelines for the non-surgical management of knee osteoarthritis. Osteoarthr Cartil. 2014;22(3):363–88.
12. Fernandes L, Hagen KB, Bijlsma JWJ, Andreassen O, Christensen P, Conaghan PG, et al. EULAR recommendations for the non-pharmacological core management of hip and knee osteoarthritis. Ann Rheum Dis. 2013;72(7):1125–35.
13. Warburton D, Nicol C, Bredin S. Health benefits of physical activity: the evidence. CMAJ. 2006;174(6):801–9.
14. Santos L, Elliot-Sale K, Sale C. Exercise and bone health across the lifespan. Biogerontology. 2017;18(6):931–46.
15. ParticipACTION. ParticipACTION. The Brain + Body Equation: Canadian kids need active bodies to build their best brains. The 2018 ParticipACTION Report Card on Physical Activity for Children and Youth. Toronto; 2018.
16. Ardern CL, Glasgow P, Schneiders A, Witvrouw E, Clarsen B, Cools A, et al. 2016 Consensus statement on return to sport from the First World Congress in Sports Physical Therapy, Bern. Br J Sports Med. 2016;50(14):853–64.
17. Ageberg E, Roos EM. Neuromuscular exercise as treatment of degenerative knee disease. Exerc Sport Sci Rev. 2015;43(1):14–22.

18. Roos EM, Dahlberg L. Positive effects of moderate exercise on glycosaminoglycan content in knee cartilage: A four-month, randomized, controlled trial in patients at risk of osteoarthritis. Arthritis Rheum. 2005;52(11):3507–14.

19. Colley RC, Carson V, Garriguet D, Janssen I, Roberts KC, Tremblay MS. Physical activity of Canadian children and youth, 2007 to 2015. Stat Canada Cat Heal Reports. 2017;28(10):8–16.

20. Montalvo AM, Schneider DK, Yut L, Webster KE, Beynnon B, Kocher MS, et al. "What's my risk of sustaining an ACL injury while playing sports ?" A systematic review with meta-analysis. Br J Sport Med. 2018;Epub:1–12.

21. Ardern CL, Taylor NF, Feller J, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. Br J Sports Med. 2014;48(21):1543–52.

22. Vos T, Flaxman AD, Naghavi M, Lozano R, Michaud C, Ezzati M, et al. Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet. 2012;380(9859):2163–96.

23. Majewski M, Susanne H, Klaus S. Epidemiology of athletic knee injuries: A 10 year study. Knee. 2006;13(3):184–8.

24. Griffin L, Agel J, Albohm M, Arendt E, Dick R, Garrett W, et al. Non-contact anterior cruciate ligament injuries: risk factors and prevention strategies. Am J Acad Orthop Surg. 2000;8(3):141–50.

25. Nielsen Sports. Global Interest in Football. https://nielsensports.com/global-interest-football/. Accessed March 19 2019.

26. Gornitzky AL, Lott A, Yellin JL, Fabricant PD, Lawrence JT, Ganley TJ. Sport-specific yearly risk and incidence of anterior cruciate ligament tears in high school athletes: a systematic review and meta-analysis. Am J Sports Med. 2016;44(10):2716–23.

27. Waldén M, Hägglund M, Werner J, Ekstrand J. The epidemiology of anterior cruciate ligament injury in football (soccer): A review of the literature from a gender-related perspective. Knee Surgery, Sport Traumatol Arthrosc. 2011;19(1):3–10.

28. Fulstone D, Chandran A, Barron M, DiPietro L. Continued sex-differences in the rate and severity of knee injuries among collegiate soccer players. Int J Sport Med. 2016;37:1150–3.

29. Duthon VB, Barea C, Abrassart S, Fasel JH, Fritschy D, Me J. Anatomy of the anterior cruciate ligament. Knee Surg Sport Tramatol Arthrosc. 2006;14:204–13.

30. Nordenvall R, Bahmanyar S, Adami J, Stenros C, Wredmark T, Fellander-Tsai L. A population-based nationwide study of cruciate ligament injury in Sweden, 2001-2009: incidence, treatment, and sex differences. Am J Sport Med. 2012;4(8):1808–13.

31. Griffin LY, Albohm MJ, Arendt EA, Bahr R, Beynnon BD, Demaio M, et al. Understanding and preventing noncontact anterior cruciate ligament injuries. Am J Sport Med. 2006;34(9):1512–32.

32. Mall N, Chalmers P, Moric M, Tanaka M, Cole B, Bach B, et al. Incidence and trends of anterior cruciate ligament reconstruction in the United States. Am J Sport Med. 2014;42(10):2363–70.

33. Logerstedt D, Snyder-Macker L, Ritter R, Axe M. Knee pain and mobility impairments: meniscal and articular cartilage lesions. J Orthop Sport Phys Ther. 2010;40(6):A1–35.

34. Brindle T, Nyland J, Johnson D. The meniscus: review of basic principles with application

to surgery and rehabilitation. J Athl Train. 2001;36:160–9.

35. Bhosale AM, Richardson JB. Articular cartilage: structure, injuries and review of management. Br Med Bull. 2008;87:77–95.

36. Solheim E, Magnus A, Peder K, Larsen A, Strand T, Brittberg M. Symptoms and function in patients with articular cartilage lesions in 1000 knee arthroscopies. Knee Surg Sport Tramatol Arthrosc. 2016;24(5):1610–6.

37. Kon E, Ronga M, Filardo G, Farr J, Madry H, Milano G, et al. Bone marrow lesions and subchondral bone pathology of the knee. Knee Surg Sport Traumatol Arthrosc. 2016;24(6):1797–814.

38. Schneider D, Grawe B, Magnussen R, Ceasar A, Parikh S, Wall E, et al. Outcomes after isolated medial patellofemoral ligament reconstruction for the treatment of recurrent lateral patellar dislocations: a systematic review and meta-analysis. Am J Sport Med. 2016;44(11):2993–3005.

39. Fithian D, Paxton E, Stone M, Siliva P, Davis D, Elias D, et al. Epidemiology and natural history of acute patellar dislocation. Am J Sport Med. 2004;32(5):114–21.

40. Nomura E, Inoue M, Kurimura M. Chondral and osteochondral injuries associated with acute patellar dislocation. Arthroscopy. 2001;19(7):717–21.

41. Pasulka J, Jayanthi N, McCann A, Dugas L, LaBella C. Specialization patterns across various youth sports and relationship to injury risk. Phys Sport. 2017;45(3):344–52.

42. Swenson D, Collins C, Best T, Flanigan D, Fields SK, Comstock RD. Epidemiology of knee injuries among US high school athletes, 2005/6-2010/11. Med Sci Sport Exerc. 2013;45(3):462–9.

43. Davison C, Russel K, Piedt S, Pike I, Pickett W. Injury among young Canadians: a

national study of contextual determinants. 2013.

44. Emery CA, Meeuwisse WH, McAllister JF. A survey of sport participation, sport injury, and sport safety practices in adolescents. . Clin J Sport Med. 2006;16:20–6.

45. Labella CR, Hennrikus W, Hewett T. Anterior cruciate ligament injuries: diagnosis , treatment, and prevention. Pediatrics. 2014;133(5):1437–50.

46. Meeuwisse W. Assessing causation in sport injury: a multi-factorial model. Clin J Sport Med. 1994;4:166–70.

47. Bahr R, Krosshaug T. Understanding injury mechanisms: A key component of preventing injuries in sport. Br J Sports Med. 2005;39(6):324–9.

48. Meeuwisse W, Tyreman H, Hagel B, Emery C. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. Clin J Sport Med. 2007;17(3):215–9.

49. Stijak L, Kadija M, Djulejic V, Askic M, Petronijevic N, Markovic B, et al. The influence of sex hormones on anterior cruciate ligament rupture: female study. Knee Surg Sport Traumatol Arthrosc. 2015;23(9):2742–9.

50. Giugliano DN, Solomon JL. ACL tears in female athletes. Phys Med Rehabil Clin N Am. 2007;18(3):417–38.

51. Shultz SJ, Schmitz RJ, Benjaminse A, Collins M, Ford K, Kulas AS. ACL research retreat VII: an update on anterior cruciate ligament injury risk factor identification, screening, and prevention. 2015;50(10):1076–93.

52. Chandrashekar N, Slauterbeck J, Hashemi J. Sex-based differences in the anthropometric characteristics of the anterior cruciate ligament and its relation to intercondylar notch geometry. Am J Sport Med. 2005;33(10):1492–8.

53. Nguyen A, Shultz S. Sex differences in lower extremity posture. J Orthop Sport Phys

Ther. 2007;37(7):389–98.

54. Shultz S, Nguyen A, Schmitz R. Differences in lower extremity anatomical and postural characteristics in males and females between maturation groups. J Orthop Sport Phys Ther. 2008;38(3):137–49.

55. Rozzi SL, Lephart SM, Gear WS, Fu FH. Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. Am J Sport Med. 1999;27(3):312–9.

56. Slauterbeck J, Fuzie S, Smith M, Clark R, Xu K, Starch D, et al. The menstral cycle, sex hormones, and anterior cruciate ligament injury. J Athl Train. 2002;37(3):275–80.

57. Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes. Am J Sport Med. 2006;34(2):299–311.

58. Hewett T, Myer G, Ford K. Decrease in neuromuscular control about the knee with maturation in female athletes. J Bone Jt Surg Am. 2004;86(8):1601–8.

59. Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo A, McLean SG, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes. Am J Sport Med. 2005;33(4):492–501.

60. Abernethy L, Bleakley C. Strategies to prevent injury in adolescent sport: a systematic review. Brit J Sport Med. 2007;41(10):627–38.

61. Valovich-McLeod TC, Bay RC, Parsons JT, Sauers EL, Snyder AR. Recent injury and health-related quality of life in adolescent athletes. J Athl Train. 2009;44(6):603–10.

62. Grimmer KA, Jone D, Williams J. Prevalence of adolescent injury from recreational exercise: an Austrailian perspective. J Adolesc Heal. 2000;27(4):266–72.

63. Janssen I, Leblanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. Int J Behav Nutr Phys Act. 2010;7:40.

64. Podlog L, Banham SM, Wadey R, Hannon JC. Psychological readiness to return to competitive sport following injury: a qualitative study. Sport Psychol. 2015;29:1–14.

65. Johnston LH, Carroll D. The context of emotional responses to athletic injury: a qualitative analysis. J Sport rehab. 1998;7:206–20.

66. Ebert J, Edwards P, Yi L, Joss B, Auckland T, Carey-Smith R, et al. Strength and functional symmetry is associated with post-operative rehabilitation in patients following anterior cruciate ligament reconstruction. Knee Surg Sport Traumatol Arthrosc. 2018;26(8):2353–61.

67. Hunter DJ, Schofield D, Callander E. The individual and socioeconomic impact of osteoarthritis. Nat Rev Rheumatol. 2014;10(7):437–41.

68. Dieppe P. Developments in osteoarthritis. Rheumatology. 2011;50(2):245–7.

69. Murphy L, Schwartz TA, Helmick CG, Renner JB, Tudor G, Koch G, et al. Lifetime risk of symptomatic knee osteoarthritis. Arthritis Rheum. 2008;59(9):1207–13.

70. Oiestad, BE, Engebretsen, L, Storheim, K, Risberg M. Knee osteoarthritis after anterior cruciate ligament injury: A systematic review. Am J Sport Med. 2009;37(7):1434–43.

71. Ajuied A, Wong F, Smith C, Norris M, Earnshaw P, Back D, et al. Anterior cruciate ligament injury and radiologic progression of knee osteoarthritis: a systematic review and meta-analysis. Am J Sports Med. 2014;42(9):2242–52.

72. Claes S, Hermie L, Verdonk R, Bellemans J, Verdonk P. Is osteoarthritis an inevitable consequence of anterior cruciate ligament reconstruction? A meta-analysis. Knee Surg Sport Traumatol Arthrosc. 2013;21(9):1967–76.

73. Van Ginckel A, Verdonk P, Victor J, Al. E. Cartilage status in relation to return to sports after anterior cruciate ligament reconstruction. Am J Sport Med. 2013;41:550–9.

74. van Meer B, Meuffels D, van Eijsden W, Verhaar J, Bierma-Zeinstra SM, Reijman M. Which determinants predict tibiofemoral and patellofemoral osteoarthritis after anterior cruciate ligament injury? A systematic review. Br J Sport Med. 2015;49(15):975–83.

75. Hunter D, Guermazi A, Lo G, Grainger A, Conaghan P, Boudreau R, et al. Evolution of semi-quantitative whole joint assessment of knee OA: MOAKS (MRI Osteoarthritis Knee Score). Osteoarthr Cartil. 2011;19(8):990–1002.

76. Carbone A, Rodeo S. Review of current understanding of post-traumatic osteoarthritis resulting from sports injuries. J Orthop Res. 2017;35(3):397–405.

77. Culvenor A, Collins N, Guemazi A. Early knee osteoarthritis is evident 1 year following anterior cruciate ligament reconstruction: A magnetic resonance imaging evaluation. Arthritis Rheum. 2015;67:946–55.

78. Whittaker JL, Toomey CM, Woodhouse LJ, Jaremko JL, Nettel-aguirre A, Emery CA. Association between MRI-defined osteoarthritis, pain, function and strength 3 – 10 years following knee joint injury in youth sport. Br J Sport Med. 2018;52(14):934–9.

79. Cross M, Smith E, Hoy D, Nolte S, Ackerman I, Fransen M, et al. The global burden of hip and knee osteoarthritis: estimates from the Global Burden of Disease 2010 study. Ann Rheum Dis. 2014;73:1323–30.

80. Arthritis Alliance of Canada. The impact of arthritis in Canada: today and over the next 30 years. Ottawa, On. 2011.

81. Perruccio A V., Power JD, Badley EM. Revisiting arthritis prevalence projections - it's more than just the aging of the population. J Rheumatol. 2006;33(9):1856–62.

82. Buller LT, Best MJ, Baraga MG, Kaplan LD. Trends in anterior cruciate ligament reconstruction in the United States. Orthop J Sport Med. 2015;3(1):2325967114563664.

83. Centers for Disease Control and Prevention. National Center for Chronic Diease Prevention and Health Promotion, Division of Population Health. Osteoarthritis. 2019. https://www.cdc.gov/arthritis/basics/osteoarthritis.htm Accessed March 19 2019.

84. Woolf AD, Pfleger B. Burden of major musculoskeletal conditions,. Bull World Health Organ. 2003;81(9):646–56.

85. Ma VY, Chan L, Kadir J Carruthers. The incidence, prevalence, costs and impact on disability of common conditions requiring rehabilitation in the US: stroke, spinal cord injury, traumatic brain injury, multiple sclerosis, osteoarthritis, rheumatoid arthritis, limb loss, and back pain. Arch Phys Med Rehabil. 2014;95(5):986–95.

86. Brown TD, Johnston RC, Saltzman CL, Marsh JL, Buckwalter JA. Posttraumatic osteoarthritis: a first estimate of incidence, prevalance, and burden of disease. J Orthop Trauma. 2006;20:739–44.

87. Mather R, Koenig L, Kocher MS, Dall TM, Gallo P, Scott DJ, et al. Societal and economic impact of anterior cruciate ligament tears. 2013;1751–9.

88. Sharif B, Garner R, Sanmartin C, Flanagan WM, Hennessy D, Marshall DA. Risk of work loss due to illness or disability in patients with osteoarthritis: a population-based cohort study. Rheumatol. 2016;1–8.

89. Eitzen I, Moksnes H, Mackler L, Reisberg MA. A progressive 5-week exercise therapy program leads to significant improvement in knee function early after anterior cruciate ligament injury. 2011;40(11):705–21.

90. Grindem H, Risberg MA, Eitzen I. Two factors that may underpin outstanding outcomes

after ACL rehabilitation. Br J Sports Med. 2015;49(22):1425.

91. Grevnerts HT, Fältström A, Sonesson S, Gauffin H, Carlfjord S, Kvist J. Activity demands and instability are the most important factors for recommending to treat ACL injuries with reconstruction. Knee Surgery, Sport Traumatol Arthrosc. 2018;26(8):2401–9.

92. Marx R, Jones E, Angel M, Wickiewicz T, Warren R. Beliefs and attitudes of members of the American Academy of Orthopaedic Surgeons regarding the treatment of anterior cruicate ligament injury. Arthroscopy. 2003;19(7):762–70.

93. Krutsch W, Zellner J, Baumann F, Pfeifer C, Nerlich M, Angele P. Timing of anterior cruciate ligament reconstruction within the first year after trauma and its influence on treatment of cartilage and meniscus pathology. Knee Surg Sport Traumatol Arthrosc. 2015;25(2):418–25.

94. Frobell RB, Roos HP, Roos EM, Roemer FW, Ranstam J, Lohmander LS. Treatment for acute anterior cruciate ligament tear: five year outcome of randomised trial. BMJ. 2013;346.

95. Grindem H, Granan LP, Risberg MA, Engebretsen L, Eitzen I. How does a combined preoperative and postoperative rehabilitation programme influence the outcome of ACL reconstruction 2 years after surgery ? A comparison between patients in the Delaware-Oslo ACL Cohort and the Norwegian National Knee Ligament Registry. Br J Sport Med. 2015;49(6):385–9.

96. Filbay SR, Roos EM, Frobell RB, Roemer F, Ranstam J, Lohmander LS. Delaying ACL reconstruction and treating with exercise therapy alone may alter prognostic factors for 5-year outcome: An exploratory analysis of the KANON trial. Br J Sports Med. 2017;51(22):1622–9.

97. Myklebust G, Bahr R. Return to play guidelines after anterior cruciate ligament surgery. Br J Sport Med. 2005;39:127–32.

98. Ardern CL, Ekås GR, Grindem H, Moksnes H, Anderson AF, Chotel F, et al. 2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament (ACL) injuries. Br J Sports Med. 2018;52(7):422–38.

99. Mokkink LB, Prinsen CAC, Bouter LM, de Vet HCW, Terwee CB. The COnsensus-based standards for the selection of health measurement INstruments (COSMIN) and how to select an outcome measurement instrument. Brazilian J Phys Ther. 2016;20(2):105–13.

100. Tanner SM, Dainty KN, Marx RG, Kirkley A. Knee-specific quality-of-life instruments: Which ones measure symptoms and disabilities most important to patients? Am J Sports Med. 2007;35(9):1450–8.

101. Clark N. Functional performance testing following knee ligament injury. Phys Ther Sport. 2001;2(2):91–105.

102. Almangoush A, Herrington L. Functional performance testing and patient reported outcomes following ACL reconstruction: a systematic scoping review. Int Sch Res Not. 2014;613034.

103. Grindem H, Logerstedt D, Eitzen I, Moksnes H, Axe M, Snyder-Mackler L, et al. Single-legged hop tests as predictors of self-reported knee function in non-operatively treated individuals with ACL injury. Am J Sport Med. 2011;39(11):2347–54.

104. Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: The Delaware-Oslo ACL cohort study. Br J Sports Med. 2016;50(13):804–8.

105. Mokkink L, Terwee C, Patrick D, Alonso J, Stratford P, Knol D, et al. The COSMIN study reached international consensus on taxonoy, terminology, and definitions of measurement properties for health related patient reported outcomes. J Clin Epidemiol. 2010;63(7):737–45.

106. Whittaker JL, Woodhouse LJ, Nettel-Aguirre A, Emery C. Outcomes associated with early post-traumatic osteoarthritis and other negative health consequences 3–10 years following knee joint injury in youth sport. Osteoarthr Cartil. 2015;23(7):1122–9.

107. Chmielewski TL, Zeppieri Jr. G, Lentz TA, Tillman SM, Moser MW, Indelicato PA, et al. Longitudinal changes in psychosocial factors and their association with knee pain and function after anterior cruciate ligament reconstruction. Phys Ther. 2011;91(9):1355–66.

108. Filbay SR, Culvenor AG, Ackerman N, Russell TG, Crossley KM. Quality of life in anterior cruciate ligament-deficient individuals: A systematic review and meta-analysis. Br J Sports Med. 2015;49(16):1033–41.

109. Reid A, Birmingham TB, Stratford PW, Alcock GK, Giffin JR. Hop testing provides a reliable and valid outcome measure during rehabilitation after anterior cruciate ligament reconstruction. Phys Ther. 2007;87:337–49.

110. Kline P, Johnson D, Ireland M, Noehren B. Clinical predictors of knee mechanics at return to sport following ACL reconstruction. Med Sci Sport Exerc. 2016;48(5):790–5.

111. Moksnes H, Risberg MA. Performance-based functional evaluation of non-operative and operative treatment after anterior cruiate ligament injury. Scand J Med Sci Sport. 2009;19:345–55.

112. Culvenor AG, Collins NJ, Guermazi A, Cook JL, Vicenzino B, Whitehead TS, et al. Early patellofemoral osteoarthritis features one year after anterior cruciate ligament

reconstruction: symptoms and quality of life at three years. Arthritis Care Res. 2016;68(6):784–92.

113. Thorstensson C, Petersson I, Jacobsson L. Reduced functional performance in the lower extremity predicted radiographic knee osteoarthritis five years later. Ann Rheum Dis. 2004;63(4):402–7.

114. Lynch AD, Logerstedt DS, Grindem H, Eitzen I, Hicks GE, Axe MJ, et al. Consensus criteria for defining "successful outcome" after ACL injury and reconstruction: a Delaware-Oslo ACL cohort investigation. Br J Sports Med. 2015;49(5):335–42.

115. The Euroquol Group. Euroqol – a new facility for the measurement of health-related quality-of-life. Health Policy (New York). 1990;16:190–208.

116. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynnon BD. Knee injury and osteoarthritis outcome score (KOOS)- Development of a self-administered outcome measure. J Orthop Sport Phys Ther. 1998;28(2):88–96.

117. Briggs KK, Lysholm J, Tegner Y, Rodkey WG, Kocher MS, Steadman JR. The reliability, validity, and responsiveness of the Lysholm Score and Tegner Activity Scale for anterior cruiciate ligament injuries of the knee. Am J Sport Med. 2009;37(5):890–7.

118. Webster KE, Feller JA, Lambros C. Development and preliminary validation of a scale to measure the psychological impact of returning to sport following anterior cruciate ligament reconstruction surgery. Phys Ther Sport. 2008;9(1):9–15.

119. Brewer B, Raalet V, Linder D. Athletic Identity: Hercules muscle or achilles heel. J Sport Behav. 1993;24:237–54.

120. Thomeé P, Währborg P, Börjesson M, Thomeé R, Eriksson BI, Karlsson J. A new instrument for measuring self-efficacy in patients with an anterior cruciate ligament

injury. Scand J Med Sci Sport. 2006;16(3):181–7.

121. Mokkink LB, Terwee CB, Patrick DL, Alonso J, Stratford PW, Knol DL, et al. The COSMIN checklist for assessing the methodological quality of studies on measurement properties of health status measurement instruments: An international Delphi study. Qual Life Res. 2010;19(4):539–49.

122. Mokkink LB, de Vet HCW, Prinsen CAC, Patrick DL, Alonso J, Bouter LM, et al. COSMIN Risk of Bias checklist for systematic reviews of Patient-Reported Outcome Measures. Qual Life Res. 2018;27(5):1171–9.

123. American Educational Research Association, American Psychological Association, and National Council on Measurement in Education. Standards for Educational and Psychological Testing. Washington, DC; 2014.

124. Reeves TD, Marbach-ad G. Contemporary test validity in theory and practice: A primer for discipline-based education researchers. CBE Life Sci Educ. 2016;15:1–9.

125. Messick S. Validity. In: Linn R, editor. Educational Measurement. 3rd ed. New York, NY: MacMillan; 1989. p. 13–103.

126. Guillemin F, Bombardier C. Cross-cultural adaptation of health-related quality of life measures: literature review and proposed guidelines. J Clin Epidemiol. 1993;46(12):1417–32.

127. Beaton DE, Bombardier C, Guillemin F, Ferraz MB. Guidelines for the process of cross-cultural adaptation of self-report measures. Spine (Phila Pa 1976). 2000;25(24):3186–91.

128. Wang D, Jones MH, Khair MM, Miniaci A. Patient-reported outcome measures for the knee. J Knee Surg. 2010;23(3):137–51.

129. Roos EM, Roos HP, Ekdahl C, Lohmander LS. Knee injury and osteoarthritis outcome

score (KOOS)- validation of a Swedish version. Scand J Med Sci Sport. 1998;8:439–48.

130. Cameron KL, Thompson BS, Peck KY, Owens BD, Marshall SW, Svoboda SJ. Normative values for the KOOS and WOMAC in a young athletic population: History of knee ligament injury is associated with lower scores. Am J Sports Med. 2013;41(3):582–9.

131. Skou ST, Wrigley T, Metcalf BR, Hinman RS, Bennell KL. Association of knee confidence with pain, knee instability, muscle strength, and dynamic varus-valgus joint motion in knee osteoarthritis. Arthritis Care Res. 2014;66(5):695–701.

132. Skou S, Rasmussen S, Simonsen O, Roos E. Knee confidence as it relates to self-reported and objective correlates of knee osteoarthritis: a cross-sectional study of 220 patients. J Orthop Sport Phys Ther. 2015;45(10):765–71.

133. Kvist J, Österberg A, Gauffin H, Tagesson S, Webster K, Ardern C. Translation and measurement properties of the Swedish version of ACL-Return to Sports after Injury questionnaire. Scand J Med Sci Sport. 2013;23(5):568–75.

134. Ardern C, Taylor NF, Feller JA, Whitehead TS, Webster KE. Psychological responses matter in returning to pre-injury level of sport after anterior cruciate ligament reconstruction surgery. Am J Sport Med. 2013;41(7):1549–58.

135. Thomeé P, Währborg P, Börjesson M, Thomeé R, Eriksson BI, Karlsson J. Self-efficacy, symptoms, and physical activity in patients with an anterior cruciate ligament injury: A prospective study. Scand J Med Sci Sport. 2007;17(3):238–45.

136. Flosadottir V, Frobell R, Roos EM, Ageberg E. Impact of treatment strategy and physical performance on future knee-related self- efficacy in individuals with ACL injury. BMC Musculoskelet Disord. 2018;19(1):50.

137. Nakayama H, Kanto R, Kambara S, Kurosaka K, Onishi S, Yoshiya S, et al. Clinical

outcome of meniscus repair for isolated meniscus tear in athletes. Asia Pac J Sport Med Arthrosc Rehabil Technol. 2017;10:4–7.

138. Filbay SR, Ackerman IN, Russell TG, Macri EM, Crossley KM. Health-related quality of life after anterior cruciate ligament reconstruction: A systematic review. Am J Sports Med. 2015;42(5):1247–55.

139. Ardern CL, Österberg A, Sonesson S, Gauffin H, Webster KE, Kvist J. Satisfaction with knee function after primary anterior cruciate ligament reconstruction is associated with self-efficacy, quality of life, and returning to the preinjury physical activity. Arthroscopy. 2016;32(8):1631–8.

140. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. Am J Sports Med. 2016;44(7):1861–76.

141. Toomey CM, Whittaker JL, Nettel-Aguirre A, Reimer RA, Woodhouse LJ, Ghali B, et al. Higher fat mass is associated with a history of knee injury in youth sport. J Orthop Sport Phys Ther. 2017;47(2):80–7.

142. Anderson A, Anderson C. Correlation of meniscal and articular cartilage injuries in children and adolescents with timing of anterior cruciate ligament reconstruction. Am J Sport Med. 2015;43(2):275–81.

143. Stefancin J, Parker R. First-time traumatic patellar dislocation: a systematic review. Clin Orthop Relat Res. 2007;455:93–101.

144. Paterno M, Pauh M, Schmitt L, Ford K, Al. E. Incidence of contralateral and ipsilateral anterior cruciate ligament injury after primary ACL reconstruction and return to sport. Clin J Sport Med. 2012;22(2):116–21.

145. Kvist J, Kartus J, Karlsson J, Forssblad M. Results from the Swedish national anterior cruciate ligament register. Arthroscopy. 2014;30(7):803–10.

146. Geffroy L, Lefevre N, Thevenin-Lemoine C, Peyronnet A, Lakhal W, Fayard JM, et al. Return to sport and re-tears after anterior cruciate ligament reconstruction in children and adolescents. Orthop Traumatol Surg Res. 2018;104(8S):S183–8.

147. Dekker T, Godin J, Dale K, Garrett W, Taylor D, Riboh J. Return to sport after pediatric anterior cruciate ligament reconstruction and its effect on subsequent anterior cruciate ligament injury. J Bone Joint Surg Am. 2017;99(11):897–904.

148. Kaeding C, Pedroza A, Reinke E, Huston L, Spindler K. Risk factors and predictors of subsequent ACL injury in either knee after ACL reconstruction. Am J Sport Med. 2015;43(7):1583–90.

149. Lind M, Menhert F, Pedersen A. Incidence and outcome after revision anterior cruciate ligament reconstruction: results from the Danish registry for knee ligament reconstructions. Am J Sport Med. 2012;40:1551–7.

150. Ekås GR, Ardern C, Grindem H, Engebretsen L. New meniscal tears after ACL injury: what is the risk? A systematic review protocol. Br J Sports Med. 2018;52(6):386.

151. Anderson C, Anderson C. Management of the anterior cruciate ligament-injured knee in the skeletally immature athlete. Clin Sport Med. 2017;36(1):35–52.

152. Duncan KJ, Chopp-Hurley JN, Maly MR. A systematic review to evaluate exercise for anterior cruciate ligament injuries: Does this approach reduce the incidence of knee osteoarthritis? Open Access Rheumatol Res Rev. 2016;8:1–16.

153. Myer GD, Faigenbaum AD, Barber-Foss K, Xu Y, Khoury J, Dolan LM, et al. Injury initiates unfavourable weight gain and obesity markers in youth. Br J Sport Med.

2014;48(20):1477–81.

154. Teichtahl AJ, Wang Y, Wluka AE, Cicuttini F. Obesity and knee osteoarthritis: new insights provided by body composition studies. Obesity. 2008;16(2):232–40.

155. Cicuttini FM, Wluka AE. Not just loading and age: The dynamics of osteoarthritis, obesity and inflammation. Med J Aust. 2016;204(2):47–47.e1.

156. Renstrom PA. Eight clinical conundrums relating to anterior cruciate ligament (ACL) injury in sport: recent evidence and a personal reflection. Br J Sport Med. 2013;47:367–72.

157. Fisher B, Nyland J, Brand E, Curtin B. Medial patellofemoral ligament reconstruction for recurrent patellar dislocation: a systematic review including rehabilitation and return-to-sports efficacy. Arthroscopy. 2010;26(10):1384–94.

158. Kim SG, Nagao M, Kamata K, Maeda K, Nozawa M. Return to sport after arthroscopic meniscectomy on stable knees. BMC Sports Sci Med Rehabil. 2013;5(1):23.

159. Aune K, Andrews J, Jugas J, Cain E. Return to Play After Partial Lateral Meniscectomy in National Football League Athletes. Am J Sport Med. 2014;42(8):1865–72.

160. Czuppon S, Racette BA, Klein SE, Harris-Hayes M. Variables associated with return to sport following anterior cruciate ligament reconstruction: a systematic review. Br J Sports Med. 2014;48(5):356–64.

161. Lai CCH, Ardern CL, Feller JA, Webster KE. Eighty-three per cent of elite athletes return to preinjury sport after anterior cruciate ligament reconstruction: A systematic review with meta-analysis of return to sport rates, graft rupture rates and performance outcomes. Br J Sports Med. 2018;52(2):128–38.

162. Feucht MJ, Cotic M, Saier T, Minzlaff P, Plath JE, Imhoff AB, et al. Patient expectations

of primary and revision anterior cruciate ligament reconstruction. Knee Surg Sport Traumatol Arthrosc. 2014;24(1):201–7.

163. Ardern C, Wesbster K, Taylor N, Feller J. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery two-thirds of patients have not returned by 12 months after surgery. Am J Sport Med. 2011;39(3):538–43.

164. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. Br J Sports Med. 2011;45(7):596–606.

165. Rotterund J, Siverten E, Forssblad M. Effect of meniscal and focal cartilage lesions on patient-reported outcome after anterior cruciate ligament reconstruction: a nationwide cohort study from Norway and Sweden of 8476 patients with 2-year follow-up. Am J Sport Med. 2013;41(535–43).

166. Culvenor AG, Crossley KM. Accelerated return to sport after anterior cruciate ligament injury: a risk factor for early knee osteoarthritis? Br J Sports Med. 2015;50(5):260–1.

167. Ardern CL, Khan KM. The old knee in the young athlete: knowns and unknowns in the return-to-play conversation. Br J Sport Med. 2016;50(9):505–6.

168. Frobell RB, Le Graverand MP, Buck R, Roos EM, Roos HP, Tamez-Pena J, et al. The acutely ACL injured knee assessed by MRI: changes in joint fluid, bone marrow lesions, and cartilage during the first year. Osteoarthr Cartil. 2009;17(2):161–7.

169. Poitras VJ, Gray CE, Borghese MM, Carson V, Chaput J, Janssen I, et al. Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. Appl Physiol Nutr Metab. 2016;41(6 Suppl 3):S197-239.

170. Bailey R. Physical education and sport in schools: A review of benefits and outcomes. J Sch Health. 2006;76(8):397–401.

171. Telama R. Tracking of physical activity from childhood to adulthood: a review. Obes Facts. 2009;2(3):187–95.

172. Casperson C, Powell K, Christenson G. Physical activity, exercise and physical fitness: definitions and distinctions for health-related research. Public Heal Rep. 1985;100(2):126–31.

173. World Health Organization. What is Moderate-intensity and Vigorous-intensity Physical Activity? Global Strategy on Diet, Physcial Activity, and Health. https://www.who.int/dietphysicalactivity/physical_activity_intensity/en/

174. Sylvia LG, Berstein E, Hubbard J, Keating L, Anderson E. A practical guide to measuring physical activity. J Acad Nurtr Duet. 2014;114(2):199–208.

175. Spruijt-Metz D, Wen CKF, Bell BM, Intille S, Huang JS, Baranowski T. Advances and controversies in diet and physical activity measurement in youth. Am J Prev Med. 2018;55(4):e81–91.

176. Jacobs D, Ainsworth B, Hartman T, Leo A. A simultaneous evaluation of 10 commonly used physical activitiy questionnaires. Med Sci Sport Exerc. 1993;25:81–91.

177. McKenzie T. Observational measures of children's physical activity. J Sch Health. 1991;61(5):224–7.

178. Troiano RP, Mcclain JJ, Brychta R, Chen KY. Evolution of accelerometer methods for physical activity research Richard. Br J Sport Med. 2014;48(13):1019–23.

179. Colley RC, Garriguet D, Janssen I, Craig CL, Clarke J, Tremblay MS. Physical activity of Canadian adults: Accelerometer results from the 2007 to 2009 Canadian Health Measures

Survey. Stat Canada Cat Heal Reports. 2011;22(1).

180. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert Ti, Mcdoweell M. Physical activity in the United States measured by accelerometer. Med Sci Sport Exerc. 2008;40(1):181–8.

181. Tremblay MS, Shephard RJ, Brawley LR. Research that informs Canada's physical activity guides: an introduction. Appl Physiol Nutr Metab. 2007;32:S1–S8.

182. Tremblay MS, Carson V, Chaput J-P. Introduction to the Canadian 24-Hour Movement Guidelines for children and youth: an integration of physical activity, sedentary behaviour, and sleep. Appl Physiol Nutr Metab. 2016;41:S311–S327.

183. Tremblay M, Warburton D, Jansseen I, Paterson D, Latimer A, Rhodes R, et al. New Canadian physical activity guidelines. Appl Physiol Nurtr Metab. 2011;36(1):36–46.

184. Piercy KL, Troiano RP, Ballard RM, Carlson SA, Fulton JE, Galuska DA, et al. The physical activity guidelines for Americans. Jama. 2018;9762:1–9.

185. Seventy-first World Health Assembly. World Health Organization global action plan on physical activity 2018–2030. 2018.

186. Kemper H, Post G, Twisk J, van Mechelen W. Lifestyle and obesity in adolescence and young adulthood: results from the Amsterdam Growth and Health Longitudinal Study. Int J Obes Relat Metab Disord. 1999;23(S3):S34–40.

187. Roberts K, Yao X, Carson V, Chaput J, Janssen I, Tremblay M. Meeting the Canadian 24-Hour Movement Guidelines for children and youth. Stat Canada, Cat no 82-003-X Heal Reports. 2017;28(10):3–7.

188. Canadian Fitness and Lifestyle Research Institute, Bulletin 02: Participation in organized physical activity and sport. Ottawa, On; 2016.

189. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJF, Martin BW. Correlates of physical

activity: why are some people physically active and others not? Lancet. 2012;380(9838):258–71.

190. Sallis J, Cervero R, Ascher W, Henderson K, Kraft M, Kerr J. An ecological approach to creating active living communities. Annu Rev Public Heal. 2006;27:297–322.

191. Sterdt E, Liersch S, Walter U. Correlates of physical activity of children and adolescents: A systematic review of reviews. Health Educ J. 2014;73(1):72–89.

192. Biddle S, Whitehead S, O'Donovan T, Nevill M. Correlates of participation in physical activity for adolescent girls: a systematic review of recent literature. J Phys Act Health. 2005;2:423–34.

193. Hubbard-Turner T, Turner MJ. Physical activity levels in college students with chronic ankle instability. J Athl Train. 2015;50(7):742–7.

194. Andrew N, Wolfe R, Cameron P, Richardson M, Page R, Bucknill A, et al. The impact of sport and active recreation injuries on physical activity levels at 12 months post-injury. Scand J Med Sci Sport. 2014;24(2):377–85.

195. Cameron KL, Peck KY, Thompson BS, Svoboda SJ, Owens BD, Marshall SW. Reference values for the Marx Activity Rating Scale in a young athletic population: history of knee ligament injury is associated with higher scores. Sports Health. 2015;7(5):403–8.

196. Pescatello L, Arena R, Riebe D, Thompson P. American College of Sports Medicine Guidelines for Exercise Testing and Prescription. 9th ed. Philadelphia: Thompson Wolters Kluwer/Lippincott Williams & Wilkins; 2014.

197. Bell DR, Pfeiffer KA, Cadmus-Bertram LA, Trigsted SM, Kelly A, Post EG, et al. Objectively measured physical activity in patients after anterior cruciate ligament reconstruction. Am J Sports Med. 2017;45(8):1893–900.

198. Dunlop D, Song J, Semanik P, Sharma L, Chang R. Physical activity levels and functional performance in the osteoarthritis initiative: a graded relationship. Arthritis Rheum. 2011;63(1):127–36.

199. Juhl C, Christensen R, Roos E, Zhang W, Lund H. Impact of exercise type and dose on pain and disability in knee osteoarthritis: a systematic review and meta-regression analysis of randomized controlled trials. Arthritis Rheumagol. 2014;66(3):622–36.

200. Wallis JA, Webster KE, Levinger P, Taylor NF. What proportion of people with hip and knee osteoarthritis meet physical activity guidelines? A systematic review and meta-analysis. Osteoarthr Cartil. 2013;21(11):1648–59.

201. Creswell J. A concise introduction to mixed methods research. Thousand Oaks, CA: Sage Publications; 2015.

202. Labuschagne A. Qualitative Research - Airy Fairy or Fundamental ? 2003;8(1):100–3.

203. Emery CA. Risk factors for injury in child and adolescent sport: a systematic review of the literature. Clin J Sport Med. 2003;13(4):256–68.

204. Bennell K, Ginckel A, O'Kean C, Al E. Patient knowledge and beliefs about knee osteoarthritis after ACL injury and reconstruction. Arthritis Care Res (Hoboken). 2016;68(8):1180–5.

205. Lopez K, Willis D. Descriptive versus interpretive phenomenology: their contributions to nursing knowledge. Qual Heal Res. 2004;14(5):726–37.

206. Corbin J, Strauss A. Basics of Qualitative Research: Grounded Theory Principles and Techniques. 3rd ed. Thousand Oaks, CA: Sage Publications; 2008.

207. Morrow SL. Quality and trustworthiness in qualitative research in counseling psychology. J Couns Psychol. 2005;52(2):250–60.

208. Peshkin A. In Search of Subjectivity One's Own. Educ Res. 1988;17(7):17–21.

209. Emery CA, Meeuswisse WH. Injury rates, risk factors, and mechanisms of injury in minor hockey. Am J Sport Med. 2006;34(12):1960–9.

210. Emery C, Meeuwisse W. Risk factors for injury in indoor compared with outdoor adolescent soccer. Am J Sport Med. 2006;34:1636–42.

211. Emery CA, Rose MS, McAllister JR, Sue M. A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial. Clin J Sport Med. 2007;17:17–24.

212. Emery CA, Meeuwisse WH, Hartmann SE. Evaluation of risk factors for injury in adolescent soccer. Am J Sports Med. 2005;33(12):1882–91.

213. Emery CA, Meeuwisse WH. The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer: a cluster-randomized controlled trial. Br J Sport Med. 2010;44:555–62.

214. Emery C, Kang J, Shrier I, Goulet C, Hagel B, Benson B, et al. Risk of injury associated with body checking among youth ice hockey players. JAMA. 2010;303:2265–72.

215. Coyne IT. Sampling in qualitative research. Purposeful and theoretical sampling; merging or clear boundaries? J Adv Nurs. 1997;26(3):623–30.

216. Sirard J, Hannan P, Cutler G. Evaluation of two self-report measures of physical activity with accelerometry in young adults. J Phys Act Heal. 2013;10(1):85–96.

217. Olson K. Essentials of Qualitative Interviewing. Walnut Creek, CA: Left Coast Publishing; 2011.

218. Ryan MR, Deci E. Self-determination theory and the facilitation of intrinsic motivation. Am Psychol. 2000;55(1):68–78.

219. Podlog L, Eklund RC. The psychosocial aspects of a return to sport following serious injury: A review of the literature from a self-determination perspective. Psychol Sport Exerc. 2007;8:535–66.

220. Filbay SR, Crossley KM, Ackerman IN. Activity preferences, lifestyle modifications and re-injury fears influence longer-term quality of life in people with knee symptoms following anterior cruciate ligament reconstruction: a qualitative study. J Physiother. 2016;62(2):103–10.

221. Kvist J, Ek A, Sporrstedt K, Good L. Fear of re-injury: A hindrance for returning to sports after anterior cruciate ligament reconstruction. Knee Surg Sport Traumatol Arthrosc. 2005;13(5):393–7.

222. Podlog L, Eklund RC. A Longitudinal Investigation of Competitive Athletes' Return to Sport Following Serious Injury. J Appl Sport Psychol. 2006;18(1):44–68.

223. Hart H, Collins NJ, Ackland DC, Crossley KM. Is impaired knee confidence related to worse kinesiophobia, symptoms, and physical function in people with knee osteoarthritis after anterior cruciate ligament reconstruction? J Sci Med Sport. 2015;18(5):512–7.

224. Clement D, Shannon VR. Injured athletes' perceptions about social support. J Sport Rehabil. 2011;20(4):457–70.

225. Yang J, Peek-Asa C, Lowe JB, Heiden E, Foster DT. Social support patterns of collegiate athletes before and after injury. J Athl Train. 2010;45(4):372–9.

226. Markus H, Kunda Z. Stability and malleability of the self-concept. J Pers Soc Psychol. 1986;51(4):858–66.

227. Brewer B. Self identity and specific vulnerability to depressed mood. J Pers. 1993;61(3):343–64.

228. Brewer BW, Cornelius AE. Self-protective changes in athletic identify following anterior cruciate ligament reconstruction. Psychol Sport Exerc. 2010;11(1):1–5.

229. Shachar B, Brewer B, Cornelius A, Petitpas A. Career decision-making, athletic identity, and adjustment difficulities among retired athletes: a comparion between coaches and non-coaches. Kinesiol Slov. 2004;10(1):71–85.

230. Sturges J, Hanrahan K. Comparing telephone and face-to-face qualitative interviewing: a research note. Qual Res. 2004;4(1):107–18.

231. Colbert CJ, Song J, Dunlop D, Chmiel JS, Hayes KW, Cahue S, et al. Knee confidence as it relates to physical function outcome in persons with or at high risk of knee osteoarthritis in the osteoarthritis initiative. Arthritis Rheum. 2012;64(5):1437–46.

232. Ageberg E, Roos E. The association between knee confidence and muscle power, hop performance, and postural orientation in people with anterior cruciate ligament injury. J Orthop Sport Phys Ther. 2016;46(6):477–82.

233. Petak S, Barbu CG, Yu EW, Fielding R, Mulligan K, Sabowitz B, et al. 2013 position development conference on bone densitometry: The official positions of the International Society for Clinical Densitometry: body composition analysis reporting. J Clin Densitom. 2013;16(4):508–19.

234. Berry PA, Wluka AE, Davies-tuck ML, Wang Y, Strauss BJ, Dixon JB, et al. The relationship between body composition and structural changes at the knee. Rheumatolgy. 2010;49(12):2362–9.

235. Hangartner T, Warner S, Braillon P, Jankowski L, Shepard J. The official positions of the international society for clinical densitometry: Acquisition of duel-energy X-ray absorptiometry body composition and considerations regarding analysis and repeatability

of measures. J Clin Densitom. 2013;16(4):520–36.

236. Royal K. Four tenets of modern validity theory for medical educaiton assessment and evaluation. Adv Med Educ Pr. 2017;8:567–70.

237. Lohmander LS, Ostenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. Arthritis Rheum. 2004;50(10):3145–52.

238. Muthuri SG, McWilliams DF, Doherty M, Zhang W. History of knee injuries and knee osteoarthritis: A meta-analysis of observational studies. Osteoarthr Cartil. 2011;19(11):1286–93.

239. Adams D, Logerstedt D, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Current Concepts for Anterior Cruciate Ligament Reconstruction: A Criterion-Based Rehabilitation Progression. J Orthop Sport Phys Ther. 2012;42(7):601–14.

240. Lee I, Shiroma E, Lobelo F, Al E. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet. 2012;380(9838):219–29.

241. Ardern CL, Taylor NF, Feller JA, Webster KE. A systematic review of the psychological factors associated with returning to sport following injury. Br J Sports Med. 2013;47(17):1120–6.

242. Ardern CL, Osterberg A, Tagesson S, Gauffin H, Webster KE, Kvist J. The impact of psychological readiness to return to sport and recreational activities after anterior cruciate ligament reconstruction. Br J Sports Med. 2014;48(22):1613–9.

243. Wallston K, Wallston B, DeVellis R. Development of the Multidimensional Health Locus of Control (MHLC) Scales. Heal Educ Monogr. 1978;6:160–70.

244. Bandura A. Social Foundations of Thought and Action: A Social Cognitive Theory. Englewood Cliffs, NJ: Prentice hall; 1986.

245. Bandura A. Self-efficacy: towards a unifying theory of behaviour change. Psychol Rev. 1977;84(2):191–215.

246. US Department of Health and Human Services, National Cancer Institute. Theory at a Glance: A Guide for Health Promotion Practice. 2005.

247. Baranowski T. Increasing fruit and vegetable consumption among 4th and 5th grade students: results from focus groups using reciprocal determinism. J Nutr Educ. 1993;25(114–327).

248. Lorig K, Sobel D, Stewart A, Brown BJ, Bandura A, Ritter P, et al. Evidence suggesting that a chronic disease self-management program can improve health status while reducing hospitalization. Med Care. 1999;37(1):5–14.

249. Van Der Horst K, Paw MJCA, Twisk JWR, Van Mechelen W. A brief review on correlates of physical activity and sedentariness in youth. Med Sci Sports Exerc. 2007;39(8):1241–50.

250. Flosadottir V, Roos EM, Ageberg E. Translation, Cross-Cultural Adaptation, and Validation of the Activity Rating Scale for Disorders of the Knee. Orthop J Sport Med. 2017;5(9):1–12.

251. Willis G. Cognitive Interviewing: A Tool for Improving Questionnarie Design. Thousand Oaks, CA: Sage Publications; 2005.

252. Mokkink L, Terwee C, Knol D, Stratford P, Alonso J, Al E. The COSMIN checklist for evaluating the methodolgical quality of studies on measurement properties: A clarification of its content. BMC Med Res Methodol. 2010;10(22).

253. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. Clin Orthop Relat Res. 1985;198:43–9.

254. Wallston K, Stein M, Smith C. Form C of the MHLC Scales: A condition-specific measure of locus of control. J Pers Assess. 1994;63(3):534–53.

255. Terwee CB, Bot SDM, de Boer MR, van der Windt DAWM, Knol DL, Dekker J, et al. Quality criteria were proposed for measurement properties of health status questionnaires. J Clin Epidemiol. 2007;60(1):34–42.

256. Streiner D. Being inconsistent about consistency: when coefficent alpha does and doesn't matter. J Pers Assess. 2003;80:217–22.

257. Bland J, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;327(8476):307–10.

258. Cohen J. Statistical Power Analysis for Behavioural Sciences. 2nd ed. Hillsdale, New Jersey: Lawrence Erlbaum Associates Inc; 1988.

259. Ardern CL. Anterior cruciate ligament reconstruction — not exactly a one-way ticket back to the preinjury level: a review of contextual factors affecting return to sport after surgery. Sports Health. 2015;7(3):224–30.

260. Erikson E. Identity and the life cycle: selected papers. Psychol Issues. 1959;1(1–171).

261. Brewer B, Petitpas A, Van Raalte J. Self-identity and young athletes. In: Knight C, Harwood C, Gould J. Sport Psychology for Young Athletes. Taylor and Francis Ltd. London, England, 2017.

262. Kjønniksen L, Torsheim T, Wold B. Tracking of leisure-time physical activity during adolescence and young adulthood: a 10-year longitudinal study. Int J Behav Nutr Phys Act. 2008;5(69).

263. Telama R, Yang X, Hirvensalo M, Raitakari O. Participation in organized youth sport as a predictor of adult physical activity: A 21-Year longitudinal study. Pediatr Exerc Sci. 2006;17:76–88.

264. Webster KE, Feller JA, Leigh WB, Richmond AK. Younger patients are at increased risk for graft rupture and contralateral injury after anterior cruciate ligament reconstruction. Am J Sport Med. 2014;42(3):641–7.

265. Brant R. Sample Size Calculator [Internet]. Columbia U of B, editor. Vancouver, BC; Available from: http://www.stat.ubc.ca/~rollin/stats/ssize/n2.html

266. Prevention C for DC and. Children's BMI Tool for Schools [Internet]. 2011. Available from: http://www.cdc.gov/healthyweight/assessing/bmi/childrens_bmi/tool_for_schools.html

267. Canada HWH. Canadian Guidelines for Body Weight Classification in Adults. 2003. Ottawa Can.

268. Roos EM, Toksvig-Larsen S. Knee injury and osteoarthritis outcome score (KOOS) - validation and comparison to the WOMAC in total knee replacement. Health Qual Life Outcomes. 2003;1(17).

269. Brewer B, Cornelius A. Norms and factorial invariance of the Athletic Identity Measurement Scale. Acad Athl J. 2001;16(103–113).

270. Wilson PM, Muon S. Psychometric properties of the Exercise Identity Scale in a university sample. Int J Sport Ex Psych. 2008;6(2):115–31.

271. Woby S, Roach N, Urmston M, Watson P. Psychometric properties of the TSK-11:a shortened version of the Tampa Scale for Kinesiophobia. Pain. 2005;117:137–44.

272. George S., Lentz TA, Jr. GZ, Lee D, Chmielewski TL. Analysis of shortened versions of

the Tampa Scale for Kinesiophobia and Pain Catstrophizing Scale for patients following anterior cruciate ligament reconstruction. Clin J Pain. 2012;28(1):73–80.

273. Noyes FR, Barber SD, Mangine RE. Abnormal lower limb symetry determined by function hop tests after anterior cruciate ligament rupture. Am J Sports Med. 1991;19(5):513–8.

274. Thorstensson CA, Petersson IF, Jacobsson LTH, Boegård TL, Roos EM. Reduced functional performance in the lower extremity predicted radiographic knee osteoarthritis five years later. Ann Rheum Dis. 2004;63(4):402–7.

275. Eastlack M, Axe M, Snyder-Mackler L. Laxity, instability, and functional outcome after ACL injury: copers versus noncopers. Med Sci Sports Exerc. 1999;31:210–5.

276. Esliger DW, Tremblay MS. Physical activity and inactivity profiling: the next generation. Can J Public Heal. 2007;98(S2):195–207.

277. Masse LC, Fuemmeler BF, Anderson CB, Matthews CE, Trost SG, Catellier DJ, et al. Accelerometer data reduction: A comparison of four reduction algorithms on select outcome variables. Med Sci Sports Exerc. 2005;37(S11):S544-54.

278. Trost SG, Mciver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. Med Sci Sports Exerc. 2005;37(S11):S531-543.

279. Belton S, O' Brien W, Wickel EE, Issartel J. Patterns of noncompliance in adolescent field-based accelerometer research. J Phys Act Health. 2013;10(8):1181–5.

280. Choi L, Liu, Z, Matthews CE BM. Validation of accelerometer wear and non-wear time classification algorithm. Med Sci Sport Exerc. 2011;43(2):357–64.

281. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. Med Sci Sports Exerc. 2011;43(7):1360–8.

282. Evenson K, Catellier D, Gill K, Ondrak K, McMurray R. Calibration of two objective measures of physical activity for children. J Sport Sci. 2008;26:1557–65.

283. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap) - A metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inf. 2009;42(2):377–81.

284. Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Ou. Arthritis Care Res. 2011;63(SUPPL. 11):S208-228.

285. Whittaker JL, Toomey CM, Nettel-aguirre A, Jaremko JL, Doyle-baker PK, Woodhouse LJ, et al. Health-related outcomes after a youth sport-related knee injury. Med Sci Sport Exerc. 2018;51(2):255–63.

286. Ekelund U, Luan J, Sherar LB, Esliger DW, Griew P, Cooper A. Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. JAMA. 2012;307(7):704–12.

287. Swain D, Franklin B. Comparison of cardioprotective benefits of vigorous versus moderate intensity aerobic exercise. Am J Cardiol. 2006;97(1):141–7.

288. Etchison W, Bloodgood E, Minton C, Thompson N, Collins M, Hunter S, et al. Body mass index and percentage of body fat as indicators for obesity in an adolescent athletic population. Sport Heal. 2011;3(3):249–52.

289. Gibson G, Timlin A, Curran S, Wattis J. The scope for qualitative methods in research and clinical trials in dementia. Age Ageing. 2004;33(4):422–6.

290. Filbay SR, Grindem H. Evidence-based recommendations for the management of anterior cruciate ligament (ACL) rupture. Best Pract Res Clin Rheumatol. 2019;(E-pub).

291. Webster K, Feller J. Expectations for return to pre-injury sport before and after anterior cruciate ligament reconstruction. Am J Sport Med. 2019;47(3):578–83.

292. McPherson A, Feller J, Hewett T, Webster K. Psychological readiness to return to sport is associated with second anterior cruciate ligament injuries. Am J Sport Med. 2019;(Epub.).

293. Webster KE, Feller JA. A research update on the state of play for return to sport after anterior cruciate ligament reconstruction. J Orthop Traumatol. 2019;20(10).

294. Hodges P, Tucker K. Moving differently in pain: a new theory to explain the adaptation to pain. Pain. 2011;152(3 suppl):S90-8.

295. Bandura A. Health promotion by social cognitive means Education & Behavior. Heal Eduv Behav. 2004;31(2):143–64.

296. Young MD, Plotnikoff RC, Collins CE, Callister R, Morgan PJ. Social cognitive theory and physical activity: a systematic review and meta-analysis. Obes Rev. 2014;15:983–95.

297. Bandura A. Self-efficacy: the exercise of control. New York: W.H Freeman and Company; 1997. 382 p.

298. Murphy L, Helmick C. The impact of osteoarthritis in the united states: a population-health perspective. Am J Nurs. 2012;112(3 Suppl 1):S13-19.

299. Rao DP, Kropac E, Do MT, Roberts KC, Jayaraman GC. Childhood overweight and obesity trends in Canada. Heal Promot Chronic Dis Prev Can. 2016;36(9):194–8.

300. Buckwalter J, Saltzman C, Brown T. The impact of osteoarthritis: implications for research. Clin Orthop Relat Res. 2004;427Suppl:S6–15.

301. Steultjens M, Dekker J, Bijilsma J. Avoidance of activity and disability in patients with

osteoarthritis of the knee: the mediating role of muscle strength. Arthritis Rheum. 2002;46(7):1784–8.

302. International ORS. Osteoarthritis: A serious disease. 2016.

303. Wesseling J, Welsing P, Bierma-Zeinstra S, Dekker J, Gorter K, Kloppengurg M, et al. Impact of self-reported comorbidity on physical and mental health status in early symptomatic osteoarthritis: the CHECK (Cohort Hip and Cohort Knee) study. Rheumatol. 2013;32(1):180–8.

304. Ratzlaff CR, Liang ML. Prevention of injury related knee osteoarthritis: opportunities for the primary and secondary prevention of knee osteoarthritis. Arthritis Res Ther. 2010;12:215.

305. (CDC). C for DC and P. Prevalence of doctor-diagnosed arthritis and arthritis-attributable activity limitation--United States, 2010-2012. MMWR Morb Mortal Wkly Rep. 2013;62(44):869–73.

306. Losina E, Weinstein AM, Reichmann WM, Burbine SA, Solomon DH, Daigle ME, et al. Lifetime risk and age at diagnosis of symptomatic knee osteoarthritis in the US. Arthritis Care Res. 2013;65(5):703–11.

307. Conaghan PG, Kloppenburg M, Schett G, Bijlsma JWJ. Osteoarthritis research priorities : a report from a EULAR ad hoc expert committee. Ann Rheum Dis. 2014;73:1442–5.

Appendices

Appendix A Qualitative interview guide

a) Physical activity and sport

Tell me about the sports or activities do you do right now.
How important are sports to you?
Tell me about your sport memories from when you were a young child.
Do you consider yourself an athlete? Why or why not?
How do you see sports being a part of your life in the future?

b) Knee injury

Tell me about your knee injury.
How did you initially deal with your injury?
Do you have any advice you would provide to someone else who had the same injury as you?
Talk me through the start of your recovery.
Can you tell me about the process of returning to sports?
Do you think you fully recovered from your injury?
Tell me if there was an upside to your injury experience?
What would you say you learned from your injury experience?
Are there any other factors that would like to discuss that are relevant to your injury or your sports participation?

c) Post-traumatic Osteoarthritis

Do you ever think about the long-term impacts of your injury?
What do you know about post-traumatic osteoarthritis?

Appendix B Key themes from young adults 3-10 years after an intra-articular knee injury on their attitudes and beliefs towards physical activity and post-traumatic osteoarthritis

B.1 Acceptance

FINDINGS	ILLUSTRATIVE QUOTES
Current Physical Activity	"So the first year I kind of took it easy [in sport]…and then the next year I just kind of went at it because I knew what to expect, and I knew what my limits were and everything." Stephanie (age 22, ACL rupture/meniscus tear, 8 years ago, surgically repaired.) "I know I'm never goanna play at the level that I could before, but I also don't have the time to play at that level, so I guess it's just kinda deal with what comes from it." Derek (age 23, meniscus tear, 5 years ago, surgically repaired.) "Yeah, I guess I've learned to adapt a little bit, you know, I don't think I ever would have gotten into cycling or learned to like spin classes or there's lots of things I wouldn't find as much joy in as I do if it hadn't happened. I quite like going for a slow stroll with the dog now, which before I wouldn't take the time to do, but learned to enjoy it." Melissa (age 23. meniscus tear, 8 years ago, surgically repaired.) "It's a little frustrating to know what I was capable of [during sport] when I was younger, kind of pre-injury.... cause I've injured both of my knees and even between injury number one and injury number two I've kind of noticed like a decline in my physical abilities. And I mean it's a little frustrating, but I don't know it's, it's just something you get used to." said Trevor (age 22, bilateral ACL rupture 6 and years ago, surgically repaired.) "After the injury, now I had to go into [sport] as a different athlete" Jessica (age 23, ACL rupture, 8 years ago, surgically repaired.)
Psychological Aspects	"People always say like, 'yeah, surgery will fix you,' but your leg will never be the same. And so you just kind of have to come to terms with that." Jessica (age 23, ACL rupture, 8 years ago, surgically repaired.) "Be mental aspect just be prepared that you're not goanna be the same athlete that you were beforehand." Casey (age 25, ACL rupture, 9 years ago, surgically repaired.) "But I wouldn't, I don't think I'd change my past or my soccer career for that. Cause it's all made me who I am too right, though." Sarah (age 24, ACL rupture, 9 years ago, surgically repaired.) "I'm very easy going so its just like it happens, it happens, you can't change it, its done, so you just kind of go along with it, see where it takes you." Sam (age 22, ACL rupture, 9 years ago, surgically repaired.) "I had a pretty like decent experience with the whole [ACL recovery] I mean like I said there's inevitable inconveniences, but I do think the pay off is you can lead a virtually normal life." Jessica (age 23, ACL rupture, 8 years ago, surgically repaired.)

Current Knee Health	" Between the hundred percent of the good knee and the eighty to ninety percent of the bad knee, I still function very well for my skiing and for, and for anything else that I do, I don't ever have any problems with it, it acts up every once in a while but other than that nothing much." Stephanie (age 22, ACL rupture/meniscus tear, 8 years ago.) "There are two options with meniscus, they can try and repair it or they just cut it out and shave it down… So [the surgeon] got in and apparently it was just kind of shredded so he said he did his best to smooth it up, but it would probably never be the same." Derek (age 23, meniscus tear, 5 years ago surgically repaired.) "I know I'm, I am hard on my knee and I don't give myself breaks and I, you know, like I wanted to run a full marathon but I know that that probably is not a good idea for me just because of my knee injury." Casey (age 25, ACL rupture, 9 years ago, surgically repaired.) "When it's painful I'm quite good at realizing when it's time to sit down and just give it a minute or take Ibuprofen, for example." Sam (age 22, ACL rupture, 9 years ago, surgically repaired.) "Just the strength and functionality of my, my knees and legs in particular from pre-injury to now has definitely decreased I mean I'm, I can definitely notice that, you know, they're not as strong now, I can't do all the same things that I was able to do pre-injury, I think I can certainly get better. Trying to kind of work towards that pre-injury physical condition, but you know I think as I think I'm in a pretty good state right now I think I can, I mean I back to playing basketball and I'm, I'm pretty happy with where I'm at." Trevor (age 22, bilateral ACL rupture, 6 and 4 years ago, surgically repaired.)
Beliefs about Post Traumatic Osteoarthritis	"I wouldn't be surprised at all if I have to get at least a knee replaced and I'm fairly okay with that." Melissa (age 23. meniscus tear, 8 years ago, surgically repaired.) "I know obviously I'm going to need knee replacements. It's going to come a time. You learn to adjust and you learn to realize that that's what's going to happen… you're going to get osteoarthritis and you're just going to have to learn to deal with it" Sarah (age 24, bilateral ACL ruptures, 7 and 9 years ago, surgically repaired.) "Sometimes when my knees hurt, I wonder what it might be like thirty years from now and it's not the best thing to think about…I try not to [think about it] as much as I can, but it does pop into my head." Sam (age 22, ACL rupture, 9 years ago, surgically repaired.) "I wouldn't be surprised at all if I have to get at least a knee replaced and I'm fairly okay with that…if making them worse over time is the price I'm going to pay to continue doing all these things that I am not happy without, then so be it." Melissa (age 23. meniscus tear, 8 years ago, surgically repaired.) "The long term impact I'm aware that there's almost a guaranteed chance because after my surgery um removing a portion of my meniscus, sewing up the rest, gives me a very good chance that I'll end up with um like arthritis, definitely early onset arthritis, in my knee and I'm conscious of that, but I'm also not too worried about it, it's something that if it comes I'll deal with it, I'll figure it out, but at this point in time I'll do whatever I can just to enjoy what I've got." Callum (age 21, meniscus tear, 8 years ago, surgically repaired.)

B.2 Resiliency & Determination

FINDINGS	ILLUSTRATIVE QUOTES
Learning Experience	"Learning more about myself. Well it's always nice to overcome something right? Like obviously this is kind of the strongest flaw in my life so far so to over come double ACL tear and keep trucking. When people say like 'you were playing soccer before you did the ACL surgery?' I was like, yeah, like of course I'm not going to stop playing soccer. … So nowadays when I look back on that it's like you know, what I just like soldier on through everything now, because I've always done it like my entire like growing up I've had to keep pushing on." Justin (age 19, ACL rupture, 8 years ago, surgically repaired.) "I don't think I would have been the athlete I am if I didn't get my ACL reconstructions either. You learn time management, you learn things like perseverance, I dunno they make you better people." Sarah (age 24, bilateral ACL ruptures, 7 and 9 years ago, surgically repaired.) "That half a year I spent just not doing anything was, was quite different…I tried to entertain myself, but it really wasn't the easiest thing…its kind of opened my eyes to maybe appreciate [my health] more." Callum (age 21, meniscus tear, 8 years ago, surgically repaired.) "You learn a lot about yourself. You hopefully become stronger as in like your self-discipline and you, nothing really brings you down all that much anymore just cause you've been through worse." Jane (age 18, ACL rupture, 4 years ago, surgically repaired.) "Even though things are looking down and not a lot of fun sometimes you've just got to do what you've got to do and get through it and realize that the pain you're experiencing or the discomfort or things like that is only temporary and then just fight through it." Sam (age 22, ACL rupture, 9 years ago, surgically repaired.) "Yeah I mean I know a lot more, just in general about like sport med and just kind of like watching yourself and I don't know just like pretty much preventative stuff now like and just knowing, knowing that it can happen to you kind of changes your perspective like, okay, I do have to be careful like this can happen… and I think I took away some good from it." Jessica (age 23, ACL rupture, 8 years ago, surgically repaired.)
Motivation	"I guess knowing what motivates me…like this like having something to work towards really motivates me. For my senior year having that opportunity to, even have slim opportunity of being able to come back really motivated me to work my hardest to be just to get in that physical condition so I could come back and that's… I don't know that's just kind of probably the biggest take away is knowing that if I have that, that thing to work towards that I can really, you know, really work towards it and have that drive." Trevor (age 22, ACL rupture, 6 years ago, surgically repaired.) "I guess I was super dedicated because like I was goanna get back in, in six months and I did so." Casey (age 25, ACL rupture, 9 years ago, surgically repaired.) "I did exercises every morning. I did exercises every lunch hour at school, and then physio on the days and more exercises in the evening and then before bed as well." Sam (age 22, ACL rupture, 9 years ago, surgically repaired.)

	"And that was one of the things with having an ACL surgery or being out for that period of time was pretty hard too and just trying to get back as soon as I could and doing whatever to make sure I was on top of my exercises and not extending that recovery period." Elizabeth (age 22, ACL rupture, 6 years ago, surgically repaired.) "If there's a goal to accomplish there's nothing in the way, [I have a] very "A" type personality so I, I really worked hard and sucked it up to get to that six month recovery time so." David (age 22, tibio-femoral fracture, 7 year ago.)
Support	"My mom was always there. She was amazing, especially for the first little bit, she'd wake up three times a night to give me Tylenol. … she'd drag me to physio everyday." Alistair (age 21, ACL rupture, 6 years ago, surgically repaired.) "By then I was kind of discouraged, like I don't really want to do it now…But my dad is like, no, you can do it, you can if you still push through, you can get it." David (age 22, tibio-femoral fracture, 7 year ago.) "I mean all of my teammates are supportive in wanting me to make sure or wanting to make sure that I was, you know, doing my rehab and wanting me to come back and stuff." Trevor (age 22, ACL rupture, 6 years ago, surgically repaired.) "[My parents] were here the whole time they basically took care of me for a few months while I was getting back in all shape and everything all the driving, all the moving around to different physio's and things like that." Callum (age 21, meniscus tear, 8 years ago, surgically repaired.) "I would go to like every game, but while I couldn't play at at the same time it was motivating to keep me on, ahead of rehab." Elizabeth (age 22, ACL rupture, 6 years ago, surgically repaired.) "My friends still came over to my house and we just watch movies and play boardgames or videogames and stuff. Instead of always going out and playing football or something." Bruce (age 18, patellar dislocation, 4 years ago.) "I've been lucky that I just have a really, really, really good physio... he knows me well, he knows that I won't do [exercises] on my own."" Melissa (age 23. meniscus tear, 8 years ago, surgically repaired.)

B.3 Knee confidence

FINDING	ILLUSTRATIVE QUOTE
Caution	"I'm still nervous about re-injuring my knee I'm very cautious because I know how it happened, so I avoid situations like that. I wouldn't say its paranoid me or anything, but its opened my eyes to what could happen." David (age 22, tibio-femoral fracture, 7 year ago.) "You learn that you're human and that you can get hurt and that these things they don't, they're not just a one off, like if you hurt yourself bad enough it takes time and it affects you for the rest of your life and so you just learn to be careful. I don't think it stops me necessarily from doing anything, but you just kind of think twice all the time, like oh like do I really want to risk going through that whole process again, just because I didn't take two extra seconds to think, you know, so, I think it just made me a more cautious person in general." Jessica (age 23, ACL rupture, 8 years ago, surgically repaired.) "I just don't want to push like running is one of those things I don't do too intensely and then just like squats and things like that I'm just very mindful of not hurting [my knees]…I stopped doing like trampoline or anything like that, anything that would impact on the knee." Carly (age 23, ACL/meniscus, 9 years ago, surgically repaired.) "There's always going to probably be thoughts about making sure I don't push myself too hard in one direction and do different things, but for the most part there isn't much to worry about." Callum (age 21, meniscus tear, 8 years ago, surgically repaired.) "I had some hesitations; I noticed when I did play. It took me a couple of games to be not so hesitated that go somewhere that I was, somewhere I had to be, not worry about my knee getting knocked, or if somewhere I have to turn or be in the boards kind of thing." (Nick, age 26, patellar dislocation, 8 years ago.) "I started becoming more and more cautious because [the doctor] was really like worried and like he was really upset that I didn't have the strength I was supposed to in my knees" Justin (age 19, ACL rupture, 8 years ago, surgically repaired.) "I'm still always thinking and just always a little bit cautious about making certain movements, um flexing too much here or there if I'm running." Callum (age 21, meniscus tear, 8 years ago, surgically repaired.) "I am always conscious of like trying to avoid certain movements that would normally hurt my knee, right?" Justin (age 19, ACL rupture, 8 years ago, surgically repaired.)
Awareness	"So you just kind of keep an eye on it, it's just always in the back of your mind. I think about it on a daily basis I would say, like I don't worry or obsess over it, but its just kind of its extensive that you're aware of it most of the time. And probably because my leg has never felt the same like its not better or worse in any way, it's just kind of, it's just different." Jessica (age 23, ACL rupture, 8 years ago, surgically repaired.) "I'm not going to risk anything, so in that way I'm still conscious of my knee, but I'm not like afraid of [re-injury]." Justin (age 19, ACL rupture, 8 years ago, surgically repaired.)

	"I think it's just in the back of my mind now. I guess I don't feel like fully recovered because its something you always think about. You always have to watch it." Casey (age 25, ACL rupture, 9 years ago, surgically repaired.) "I can still feel the difference actually when I'm not wearing my brace and doing sports…I can definitely still feel it and I know it's not it won't get better its just the way it is if it hasn't gotten better in eight years its not going to get better." Stephanie (age 22, ACL rupture/meniscus tear, 8 years ago, surgically repaired.) "I was in university like just for fun I'd run on the track there and I was jumping hurdles again and stuff and I had no issues… it's just like in my own head that…I don't want to chance a re-injury." Amy (age 25, ACL rupture/meniscus, 7 years ago, surgically repaired.)
Recovery and Return to Sport	"I was fearful of doing anything to hurt [my knee] so I didn't really get into sports. I didn't want to run, I didn't want to do anything to compromise it after going through two surgeries." Carly (age 23, ACL/meniscus, 9 years ago, surgically repaired.) "Yeah I just figured…I don't feel like I'm in any pain and I feel like I have a good enough range of motion so I'm like well there's only one way to find out if its goanna get re-injured or not ." Jessica (age 23, ACL rupture, 8 years ago, surgically repaired.) "Well I'm playing sports, I definitely think about them more often, than not, ahmm, but I say a lot it wouldn't be something that I think about going into a soccer practice at all anymore. I mean when I was injured, when I was coming back from rehab, that's all you think about right, but now I'm not very concerned about going into a practice or a game." Sarah (age 24, bilateral ACL ruptures, 7 and 9 years ago, surgically repaired.) "So I had to go into it as a different athlete, like being kind of just being wary of the leg, being always thinking about it like when you have two good legs like you just kind of don't think about it." Jessica (age 23, ACL rupture, 8 years ago, surgically repaired.) "I guess I don't feel like fully recovered because it's something you always think about…You always have to watch it, so I guess never." Casey (age 25, ACL rupture, 9 years ago, surgically repaired.) "I was always confident that I was going to get back, but I think it was when I did get back to playing that's when I kind of lost interest in soccer and it wasn't as much fun. And I think it was partially because there was that whole mental barrier of not wanting this happen or this injury to happen again. So I definitely lost confidence in how I was playing and it kind of showed on the field, too not as aggressive for the ball and so it kind of skewed my perception of playing soccer." Elizabeth (age 22, ACL rupture, 6 years ago, surgically repaired.)

B.4 Athletic Identity

FINDING	ILLUSTRATIVE QUOTES
Sense of Self As Athlete	"I think that' (being an athlete) is a pretty important part of who I am," Trevor (age 22, bilateral ACL rupture, 6 and 4 years ago, surgically repaired.) "I still do… even if I'm not playing sports competitively at the moment, I consider myself a competitor." Callum (age 21, meniscus tear, 8 years ago surgically repaired.) "I guess I'm still pretty competitive, but I, I just don't have the desire really to win like to go as hard as I used to. So it's definitely more of a social like seeing my friends and stuff." Amy (age 25, ACL rupture/meniscus, 7 years ago, surgically repaired.) "I'd like to become fit, but not necessarily an athlete. The way I am right now I'm very comfortable with, I don't really care, but everybody else says its bad for your health that you look better when you're thinner. It would be fun to be fit again, be able to run wherever I want to, but its not particularly high up on my list." David (age 22, tibio-femoral fracture, 7 year ago.) "And hopefully [being an athlete] will still be that important later on and I mean I guess I would consider myself more of an athlete when I was playing at a competitive level. I think physical activity has become more of a healthy habit, more than just like competitive, athletic." Elizabeth (age 22, ACL rupture, 6 years ago, surgically repaired.) "Certainly, I mean when I was kind of involved in high level basketball I considered myself more of an athlete and I was, I think that image might have changed a little bit." Trevor (age 22, bilateral ACL ruptures, 6 and 4 years ago, surgically repaired.)
Change in Importance of Sport	"I think especially since high school it's changed, ah when I was in high school playing on the school team, our team was pretty competitive and we all were always in contention for city championship and provincial championship so it was pretty, pretty intense at that, at that time. Then kind of since then I don't know its kind of I guess drop off important compared to other things." Trevor (age 22, bilateral ACL ruptures, 6 and 4 years ago, surgically repaired.) "[Sports] are not as big a part as they used to be." Jane (age 18, ACL rupture, 4 years ago, surgically repaired.) "I've done mostly just team sports my whole life and so now I'm not in college anymore and so I'm just not really… there's no opportunity for it, or it's not as accessible so, yeah. Maybe not team sports, I do like to run, kind of like what I do when I work out alone is just a lot of cardio." Jessica (age 23, ACL rupture, 8 years ago, surgically repaired.) "I guess its not as important as it used to be, but that's because of some personal stuff that's happened and ah I started travelling, so travelling has kind of gone up on my list and rodeo has gone a bit down.I guess I'm still pretty competitive, but I, I just don't have the desire really to win like to go as hard as I used to.. so it's definitely more of a social like seeing my friends and stuff.…I'd done everything I could, like all I would be doing is the same thing over and over winning the same awards over and over and then like I got into travelling and so it kind of, rodeo was a bit expensive so I kind of put it on the back burner a bit to save money. I don't think is a result of my knee injury it's just the result of some personal, like things changing and

	getting more career focused and focused on like doing other things and volunteering." Amy (age 25, ACL rupture/meniscus, 7 years ago, surgically repaired.) "I've kinda stopped my whole sports and training and so for the last two years, hmmm I've just pretty much strictly been going to school. I've played a little bit of hockey every once in a while with some friends, but ah, yeah, other than that, it's been pretty low key now." Alistair (age 21, ACL rupture, 6 years ago, surgically repaired.) "I'm going to say pretty important right now, yeah. It hasn't changed. I spend a huge majority of my out of my school time doing it and most if my friends are from volleyball too." Tracey (age 16, patellar dislocation, 4 years ago.) "I think especially since high school it's changed… it was pretty, pretty intense at that, at that time…since then I don't know…I guess it has dropped off in importance compared to other things… I think that my image might have changed a little bit." Trevor (age 22, bilateral ACL ruptures, 6 and 4 years ago surgically repaired.) "Probably [sports are] less important now just because I work full time and don't have as much time to play soccer as I used to." Derek (age 23, meniscus tear, 5 years ago, surgically repaired.)
New Role in Sport	"I really am happy that I now have found other sports and I kind of play almost for myself or exercise for myself, rather than to, you know, to be to make a spot on the team or be a part of that… kind of very, very intense team atmosphere which is was really fun while I was in high school, but I like it was too serious like I didn't have enough time for school or for other things that I was interested in, I guess so I do think that in a way [the injury] was a huge upside because it changed the like the idea of sport from, from something that you have to do and compete in and be on like one of the top teams - to something that you can just do it for yourself and enjoy it for yourself." Matthew (age 21, meniscus tear, 4 years ago, surgically repaired.) "Yeah, I think I've kind of changed to the individualized [sport]. . . . working full time you kind of like especially being a nurse my shifts are all over the place I can't really fit anything that's the same time every time of the week you kind of have to fit it in when you can, so there has to be that flexibility. And I kind of don't want to [play team sports]," Carly (age 23, ACL/meniscus, 9 years ago, surgically repaired.) "One of my teachers…asked if I wanted to help out and I said, yes, and I've kind of been coaching ever since in some capacity. In the past five or so years I've been the head coach of one team or another…I'm really enjoying that." Trevor (age 22, bilateral ACL ruptures, 6 and 4 years ago, surgically repaired.) "When I did tear my ACLs, I was like twelve, thirteen, like of course, when you're a twelve year old you're going to think you're going to play hockey for the rest of your life. So now obviously I would never consider sports professionally, but I don't know if that's simply because of my knees or because that's not what I have a passion in, it's really fun and I'm going to play sports recreationally my whole life, but I would never consider it professionally." Justin (age 19, ACL rupture, 8 years ago, surgically repaired.)

Appendix C K-SES cognitive interview guide

Instructions for Participant

I: Thank you for agreeing to take part in this study. Today we are going to be testing a new questionnaire Let me explain how this will work. Normally, the questionnaire is designed to be filled out by participants independently. But today, because our goal is to get a better idea that the questions are asking what we think they are asking and will tell us what we need to know, I'll be getting you to *'think aloud'* as you answer each question. We will try a practice question together in a minute.

I may also ask you some further questions about terms or phrases or what you think a question is asking as we go. As well I'll be taking notes so I can remember your key points.

Please remember that I really want to hear all of your opinions and reactions to the questions, so don't hesitate to speak up especially if something is unclear, hard to answer, or doesn't seem to apply to you.

Do you have any questions before we begin the interview?

Practice Question
I: Let's begin with a practice question. Remember to try to think aloud as you answer.
How many windows are there in the house or apartment where you live?
I: How did you come up with that answer?

Interview

I: Okay let's begin the questionnaire together. Please go ahead and 'think aloud'.

General Instructions - Probes
-Can you tell me in your own words, what is the overall purpose of the questionnaire?

Section A: Daily Activities - Probes
-Was it easy or difficult to decide what answer to give?
-Are these activities relevant to you?
-Was it hard to come up with an answer?

Section B: Sports and Leisure Activities -Probes
-Is there enough detail given in the questions?
-Are there any other sports not listed that you feel very uncertain about?

Section C: Physical Activities -Probes
-What does the term 'squat' mean to you when it's used in this question?
-What does the term 'work out hard' mean to you when it's used in this question?

Section D: Knee Function in Future - Probes
-What time frame does the “future” mean to you?
-How did you come up with these answers in this section?

Summary:
-Were there any questions in particular that were hard to answer or unclear?
-What does the term ‘certain’ mean to you the way it is used in this questionnaire?

Appendix D Knee Self-Efficacy Scale

The **Knee Self-Efficacy scale** is a questionnaire regarding how confident you feel in your ability to perform different activities **right now** and how confident you feel about your knee function **in the future.**

You should base your answers on **your perception of how confident you are in your ability** to perform the different activities and not about how well you actually perform them. If you have never tried the activity, please base your answer on how confident **you think you are.**

Present knee self-efficacy: movements and actions

Check the box for the number that best describes ***how confident you are in your ability*** to perform the activity ***right now*** regardless of pain/discomfort.

0 = Not confident at all **10 = Very confident**

How confident are you in:	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Walking down stairs/down hill	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Jumping ashore from a boat	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Running after small children	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Running after a streetcar/bus	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Jumping sideways from one leg to another	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Doing a single leg hop on the injured leg	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Standing and moving around in a small, rocking boat	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Making quick changes in directions while running	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Squatting	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Present knee self-efficacy: leisure activities and sports

Check the box for the number that best describes ***how confident you are in your ability*** to perform the activity ***right now*** regardless of pain/discomfort.

0 = Not confident at all **10 = Very confident**

How confident are you in:	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Walking in the woods	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Going out dancing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Working in the garden	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cycling longer distances	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cross-country skiing	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Horseback riding	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Swimming	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hiking in the mountains	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Future knee self-efficacy

Check the box for the number that best describes ***how confident you are about*** your knee in the future.

0 = Not confident at all **10 = Very confident**

How confident are you:	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Of not having another injury to your knee	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
That you will not completely destroy your knee	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Appendix E Distributional indices for English knee self-efficacy scale

Item	Mean (SD)	Median (range)	Score Lowest (0) n, %	Score Highest (10), n, %
F1: Present knee self-efficacy: movements & actions				
Walking down stairs/down hill	7.45 (2.65)	8 (0-10)	1 (0.88)	**38 (33.04)**
Jumping ashore from a boat	5.28 (3.80)	6 (0-10)	**20 (17.39)**	**25 (21.74)**
Running after small children	5.90 (3.68)	7 (0-10)	16 (13.91)	**30 (26.09)**
Running after a streetcar/bus	5.79 (3.71)	6 (0-10)	16 (13.91)	**33 (28.70)**
Jumping sideways	5.51 (3.76)	7 (0-10)	**20 (17.39)**	**22 (19.31)**
Doing a single leg hop on injured leg	5.46 (3.56)	6 (0-10)	15 (13.04)	**20 (17.39)**
Standing/moving in a rocking boat	6.42 (3.42)	8 (0-10)	6 (5.22)	**30 (26.09)**
Quick changes of direction	4.21 (3.70)	4 (0-10)	**34 (29.57)**	15 (13.04)
Squatting	7.36 (2.75)	8 (0-10)	2 (1.74)	**36 (31.30)**
F2: Present knee self-efficacy: leisure activities & sports				
Walking in the woods	7.75 (2.77)	9 (0-10)	4 (3.48)	**46 (40.00)**
Going out dancing	5.96 (3.50)	6 (0-10)	12 (10.43)	**27 (23.48)**
Working in the garden	7.32 (3.22)	9 (0-10)	4 (3.48)	**50 (43.48)**
Cycling longer distances	7.16 (3.12)	8 (010)	7 (6.09)	**38 (33.04)**
Cross-country skiing	4.57 (3.73)	5 (0-10)	**33 (28.07)**	15 (13.04)
Horseback riding	5.57 (3.74)	6 (0-10)	**19 (16.52)**	**24 (20.87)**
Swimming	7.16 (3.17)	8 (0-10)	6 (5.22)	**40 (34.78)**
Hiking in the mountains	6.07 (3.35)	6 (0-10)	12 (10.43)	**27 (23.48)**
F3: Future knee self-efficacy				
Not having another injury to your knee$^{\beta}$	6.18 (2.39)	6 (0-10)	1 (0.88)	8 (7.08)
That you will not completely destroy your knee$^{\Sigma}$	6.67 (2.70)	7 (0-10)	3 (2.63)	**22 (19.30)**

β: n=113 $\sum$: n=114
Bold indicates presence of floor or ceiling effects

Appendix F Knee Injury and Osteoarthritis Outcome Score (KOOS)

INSTRUCTIONS: This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities.
Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Symptoms

These questions should be answered thinking of your knee symptoms during the **last week**.

S1. Do you have swelling in your knee?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S3. Does your knee catch or hang up when moving?

Never	Rarely	Sometimes	Often	Always
☐	☐	☐	☐	☐

S4. Can you straighten your knee fully?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

S5. Can you bend your knee fully?

Always	Often	Sometimes	Rarely	Never
☐	☐	☐	☐	☐

Stiffness

The following questions concern the amount of joint stiffness you have experienced during the **last week** in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

S6. How severe is your knee joint stiffness after first wakening in the morning?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

S7. How severe is your knee stiffness after sitting, lying or resting **later in the day**?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Pain

P1. How often do you experience knee pain?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

What amount of knee pain have you experienced the **last week** during the following activities?

P2. Twisting/pivoting on your knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P3. Straightening knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P4. Bending knee fully

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P5. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P6. Going up or down stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P7. At night while in bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P8. Sitting or lying

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

P9. Standing upright

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, daily living

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A1. Descending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A2. Ascending stairs

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A3. Rising from sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A4. Standing

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A5. Bending to floor/pick up an object

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A6. Walking on flat surface

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A7. Getting in/out of car

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A8. Going shopping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A9. Putting on socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A10. Rising from bed

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A11. Taking off socks/stockings

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A12. Lying in bed (turning over, maintaining knee position)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A13. Getting in/out of bath

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A14. Sitting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A15. Getting on/off toilet

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

A17. Light domestic duties (cooking, dusting, etc)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Function, sports and recreational activities

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the **last week** due to your knee.

SP1. Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP2. Running

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP3. Jumping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP4. Twisting/pivoting on your injured knee

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

SP5. Kneeling

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Quality of Life

Q1. How often are you aware of your knee problem?

Never	Monthly	Weekly	Daily	Constantly
☐	☐	☐	☐	☐

Q2. Have you modified your life style to avoid potentially damaging activities to your knee?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Q3. How much are you troubled with lack of confidence in your knee?

Not at all	Mildly	Moderately	Severely	Extremely
☐	☐	☐	☐	☐

Q4. In general, how much difficulty do you have with your knee?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Thank you very much for completing all the questions in this questionnaire.

Appendix G Godin Leisure-Time Exercise Questionnaire

Godin Leisure-Time Exercise Questionnaire

1. During a typical **7-Day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your free time (write on each line the appropriate number).

	Times Per Week
a) **STRENUOUS EXERCISE** **(HEART BEATS RAPIDLY)** (e.g., running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)	_____
b) **MODERATE EXERCISE** **(NOT EXHAUSTING)** (e.g., fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)	_____
c) **MILD EXERCISE** **(MINIMAL EFFORT)** (e.g., yoga, archery, fishing from river bank, bowling, horseshoes, golf, snow-mobiling, easy walking)	_____

2. During a typical **7-Day period** (a week), in your leisure time, how often do you engage in any regular activity **long enough to work up a sweat** (heart beats rapidly)?

OFTEN	SOMETIMES	NEVER/RARELY
1. ☐	2. ☐	3. ☐

Appendix H Knee Self-Efficacy Scale: Project Specific Questions

Today's Date: _____

Date of Birth (month and year only):_____

Describe your knee injury: _____

_____

Did you have surgery? yes ☐ no ☐ If yes, date: _____

Please describe surgery: _____

_____

Age at Injury: _____

Have you returned to sport since the injury? _____

Total amount of time off sport: _____

Have you returned to your previous activity level? _____

Are you satisfied with your current knee function and activity level? yes ☐ no ☐

Appendix I Tegner Activity Level Scale

Please indicate in the spaces below the HIGHEST level of activity that you participated in BEFORE YOUR INJURY and the highest level you are able to participate in CURRENTLY.

BEFORE INJURY: _____

CURRENT: _____

Level 10	Competitive sports- soccer, football, rugby (national or elite)
Level 9	Competitive sports –soccer, football, rugby (lower divisions), hockey, wresting, gymnastics, basketball
Level 8	Competitive sports – racquetball or bandy, squash or badminton, track and field athletics (jumping, etc), downhill skiing
Level 7	Competitive sports – tennis, running, motorcars speedway, handball Recreational sports – soccer, football, rugby, bandy, ice hockey, basketball, squash, racquetball, running
Level 6	Recreational sports – tennis and badminton, handball, racquetball, down-hill skiing, jogging at least 5 times/week
Level 5	Work – heavy labour (construction) Competitive sports – cycling, cross country skiing Recreational sports – jogging on uneven ground at least twice weekly
Level 4	Work – moderate heavy labour (truck driving, etc)
Level 3	Work – light labour (nursing, etc)
Level 2	Work light labour Walking on uneven ground possible, but impossible to backpack or hike
Level 1	Work - sedentary (secretarial)
Level 0	Sick leave or disability pension because of knee problems

Appendix J Anterior Cruciate Ligament -Return to Sport Scale

Instructions: Please answer the following questions referring to your main sport prior to injury. For each question tick a box ☑ between the two descriptions to indicate how you are feeling right now relative to the two extremes.

1. Are you confident that you can perform at your previous level of sport participation?

Not at all confident	0	10	20	30	40	50	60	70	80	90	100	Fully confident
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

2. Do you think that you are likely to re-injure your knee by participating in your sport?

Extremely likely	0	10	20	30	40	50	60	70	80	90	100	Not likely at all
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

3. Are you nervous about playing your sport?

Extremely nervous	0	10	20	30	40	50	60	70	80	90	100	Not nervous at all
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

4. Are you confident that your knee will not give way by playing your sport?

Not at all confident	0	10	20	30	40	50	60	70	80	90	100	Fully confident
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

5. Are you confident that you could play your sport without concern for your knee?

Not at all confident	0	10	20	30	40	50	60	70	80	90	100	Fully confident
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

6. Do you find it frustrating to have to consider your knee with respect to your sport?

Extremely frustrating	0	10	20	30	40	50	60	70	80	90	100	Not at all frustrating
		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

7. Are you fearful about re-injuring your knee by playing your sport?

Extremely fearful	0	10	20	30	40	50	60	70	80	90	100	No fear at all
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

8. Are you confident about your knee holding up under pressure?

Not at all confident	0	10	20	30	40	50	60	70	80	90	100	Fully confident
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

9. Are you afraid of accidently injuring your knee by playing your sport?

Extremely afraid	0	10	20	30	40	50	60	70	80	90	100	Not at all afraid
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

10. Do thoughts of having to go through surgery and rehabilitation again prevent you from playing your sport?

All of the time	0	10	20	30	40	50	60	70	80	90	100	None of the time
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

11. Are you confident in your ability to perform well at your sport?

Not at all confident	0	10	20	30	40	50	60	70	80	90	100	Fully confident
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

12. Do you feel relaxed about playing your sport?

Not at all relaxed	0	10	20	30	40	50	60	70	80	90	100	Fully relaxed
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

Appendix K Multi-Dimensional Health Locus of Control Scale

Instructions: Each item below is a belief statement about your medical condition with which you may agree or disagree. Beside each statement is a scale which ranges from strongly disagree (1) to strongly agree (6). For each item we would like you to circle the number that represents the extent to which you agree or disagree with that statement. The more you agree with a statement, the higher will be the number you circle. The more you disagree with a statement, the lower will be the number you circle. Please make sure that you answer **EVERY ITEM** and that you circle **ONLY ONE** number per item. This is a measure of your personal beliefs; obviously, there are no right or wrong answers.

1=STRONGLY DISAGREE **(SD)** 2=MODERATELY DISAGREE **(MD)** 3=SLIGHTLY DISAGREE **(D)**	4=SLIGHTLY AGREE **(A)** 5=MODERATELY AGREE **(MA)** 6=STRONGLY AGREE **(SA)**

		SD	**MD**	**D**	**A**	**MA**	**SA**
1	If my condition worsens, it is my own behavior which determines how soon I will feel better again.	1	2	3	4	5	6
2	As to my condition, what will be will be.	1	2	3	4	5	6
3	If I see my doctor regularly, I am less likely to have problems with my condition.	1	2	3	4	5	6
4	Most things that affect my condition happen to me by chance.	1	2	3	4	5	6
5	Whenever my condition worsens, I should consult a medically trained professional.	1	2	3	4	5	6
6	I am directly responsible for my condition getting better or worse.	1	2	3	4	5	6
7	Other people play a big role in whether my condition improves, stays the same, or gets worse.	1	2	3	4	5	6
8	Whatever goes wrong with my condition is my own fault.	1	2	3	4	5	6
9	Luck plays a big part in determining how my condition improves.	1	2	3	4	5	6
10	In order for my condition to improve, it is up to other people to see that the right things happen.	1	2	3	4	5	6
11	Whatever improvement occurs with my condition is largely a matter of good fortune.	1	2	3	4	5	6
12	The main thing which affects my condition is what I myself do.	1	2	3	4	5	6
13	I deserve the credit when my condition improves and the blame when it gets worse.	1	2	3	4	5	6
14	Following doctor's orders to the letter is the best way to keep my condition from getting any worse.	1	2	3	4	5	6
15	If my condition worsens, it's a matter of fate.	1	2	3	4	5	6
16	If I am lucky, my condition will get better.	1	2	3	4	5	6
17	If my condition takes a turn for the worse, it is because I have not been taking proper care of myself.	1	2	3	4	5	6
18	The type of help I receive from other people determines how soon my condition improves.	1	2	3	4	5	6

Appendix L Activity after ACL: study specific questions

Please know that providing this information is voluntary and you do not have to answer any questions that you do not want to answer.

Injury group:

A. General background information

Name:_____

Date of Birth:_____ (day/month/year)

B. Knee Injury Details

Describe how you injured your knee: _____

Date of Injury: _____ (day/month/year)

Injured knee: Left or Right

Injured Structure: (check all that apply):

Anterior Cruciate ligament ☐
Posterior Cruciate ligament ☐
Medial Collateral Ligament ☐
Lateral Collateral Ligament ☐
Meniscus (medial or lateral) ☐

Surgeon:_____ **Date of Surgery:**_____

Did you do physiotherapy for your knee at any point? Yes or No

Pre-surgery	**Yes or No**	**Number of visits**
Post surgery	**Yes or No**	**Number of visits**

If yes, when did you stop physiotherapy (i.e. 4 months post-surgery):_____

Have you had previous knee injuries, please describe if yes:_____

C. Sport and Physical Activity Details

What sports/physical activities were you participating in at the time of your knee injury (please list all):

Sport/activity:	**Frequency: (i.e. hours/week)**
_____	_____
_____	_____
_____	_____
_____	_____

What sports/physical activities are you participating in now (including physiotherapy, strengthening):

Sport/activity:	**Frequency: (i.e. hours/week)**
_____	_____
_____	_____
_____	_____
_____	_____

Have you returned to performance at main sport? (i.e. performing at or above pre-injury level)

- ○ **Yes** If yes, how long after surgery_____
- ○ **No**

Have you returned to your main sport? (i.e. returned but not performing at desired level)

- ○ **Yes** If yes, how long after surgery_____
- ○ **No**

Have you returned to 'participation' of your main sport? (i.e., training/practice only,casual or lower competitive level)

- ○ **Yes** If yes, how long after surgery_____
- ○ **No**

Control group:

A. General background information

Name:_____

Date of Birth:_____(day/month/year)

Current age: _____

Address: _____ **Phone:** _____

_____ **Email:** _____

B. Sport and Physical Activity Details

What sports/physical activities were you participating approximately 1 year ago (please list all):

Sport/activity:	**Frequency: (i.e. 2x week, 3x/month)**
_____	_____
_____	_____
_____	_____
_____	_____

What sports/physical activities are you participating in now (including physiotherapy, strengthening):

Sport/activity:	**Frequency: (i.e. 2x week, 3x/month)**
_____	_____
_____	_____
_____	_____
_____	_____

Appendix M Athletic Identity Measurement Scale

	Strongly Disagree						Strongly Agree
1. I consider myself an athlete	1	2	3	4	5	6	7
2. I have many goals related to sport	1	2	3	4	5	6	7
3. Most of my friends are athletes	1	2	3	4	5	6	7
4. Sport is the most important part of my life	1	2	3	4	5	6	7
5. I spend more time thinking about sport than anything else	1	2	3	4	5	6	7
6. I need to participate in sport to feel good about myself	1	2	3	4	5	6	7
7. Other people see me mainly as an athlete	1	2	3	4	5	6	7
8. I feel bad about myself when I do poorly in sport	1	2	3	4	5	6	7
9. Sport is the only important thing in my life	1	2	3	4	5	6	7
10. I would be very depressed if I were injured and could not compete in sport	1	2	3	4	5	6	7

Appendix N Tampa Scale of Kinesiophobia (11 item)

1=strongly disagree
2=disagree
3=agree
4=strongly agree

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