Anterior Cruciate Ligament Injury and Safe Return to Activity in Athletes and Military

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Young athletes and military members comprise a population frequently affected by anterior cruciate ligament (ACL) injury. Both are high risk for failure to return to preinjury levels of activity and reinjury. In this dissertation, we investigated trends and risk factors for ACL Injury within the US military and examined predictors of safe return to activity after ACL reconstruction (ACLR).

Using a US military database, we conducted an epidemiological retrospective cohort study of US service members from 2006 to 2018 to investigate the effects of military occupation, sex, rank, and branch of service on the risk of ACL injury over time. There was a 4.1% decline in the incidence of ACL injuries with a steeper decline seen in males compared to females. The risk of ACL injury by sex was modified by rank and occupational category was a significant risk factor. Despite the decline in ACL injuries over time, the rates of ACL injury remain much higher than the civilian population.

In our systematic review and meta-analysis, we investigated which measures of physical function predict return to sport and/or military duty and reinjury after ACLR. Seven studies were included and reported that activity level, lower extremity strength, hop tests, and movement quality may be important for safe return to sport. The pooled analysis indicated that individual limb performance on the side hop may provide an indication of who will return to preinjury level of sport. This study helped to inform the predictor measures included for our final aim.

Finally, our prospective cohort study found that for athletes at high risk for reinjury, 63% safely returned to sport and 7% sustained a reinjury by 1 year after ACLR. Those who safely returned to sport had higher future knee self-efficacy. This body of work updated our understanding of ACL injury in the US military, reinforced the importance of psychosocial measures, and highlighted the multifactorial nature of safe return to sport after ACLR.

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Preface

This dissertation is dedicated to my husband, Manny, who never stopped believing in me.

I began this journey while stationed in Guantanamo Bay, Cuba with a lot of encouragement to start the application process five years ago. I look back at that time, when there were no children yet and only a slight notion of what I was getting into, and I am in awe of what a journey this has been. I would not have made it to this point without the support of my family, friends, and mentors.

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1.0 Introduction

Anterior cruciate ligament (ACL) injury and subsequent reconstruction is common with over 130,000 ACL injuries that result in reconstruction each year in the United States, and the rate of ACL reconstructions (ACLR) continues to increase.[1,2] Two populations that are frequently affected by ACL injury and reconstruction are young athletes and military members. Within an athletic population, more than 20% of knee injuries involve injury to the ACL and more than 75% of ACL injuries result in surgery in the United States.[3] After ACL reconstruction (ACLR), the long process of rehabilitation and resumption of normal activity begins, but not everyone will safely return to preinjury level of activity. While almost all will fully return to work after ACLR within the general population,[4] return to activity outcomes are much lower in in populations with higher levels of exposure to knee strenuous activity. Up to one in three young athletes[5] and military members[6] will not resume preinjury level of activity. Furthermore, of highly active, young athletes who have undergone ACLR, one in five may suffer reinjury to either the surgically reconstructed or contralateral knee.[7]

While return to activity has been defined along a continuum, athletes and military members at different stages of their careers have a variety of factors that can positively or negatively affect their return to activity and are poorly understood. Identifying who is most likely to return to activity and avoid reinjury following ACLR is of great interest to all involved in the shared decision-making process. The consequences of ACL injury and subsequent reconstruction are wide-ranging.[8] Physical and neuromuscular changes which are reflected in return to sports testing to measure impairments in body structure and function and activity limitations have been recognized for their role in return to sport.[5] In recent years, contextual factors such as surgical, personal, environmental, social, and psychological factors have been recognized for their role in return to preinjury level of sport and performance,[9,10] however, the prognostic impact of these factors is presently unknown.

1.1 Problem Statement

The physician, physical therapist, and/or athletic trainer have the challenging task of providing advice to a patient after ACLR on when they are likely ready for return to activity based on knowledge of their injury, rehabilitation progress and clinical testing after surgery, the risk of reinjury due to specific physical demands in the particular sport or activity, and the patient's values and goals. Safe return to activity after ACLR implies that the patient not only returns to activity but does so without incurring additional ACL injury to either knee. This task is particularly difficult as there are no set tests or measures that are agreed upon and have been determined to be predictive of safe return to sport or activity.[10] In athletes, it is now more common to use criteria-based return to sport testing rather than time alone, but there is great variability in the criteria used and a lack of consistent testing protocols to determine when it is appropriate for an athlete to return to sport.[11]

In military members, ACL injury and failure to return to duty presents a clear unit readiness issue.[6] The rate of ACL injury in the U.S. military has been cited as high as 10 times the incidence of the general population from a study period that ended in 2003,[12,13] and, therefore, an updated understanding of the epidemiology of ACL injury in the military is required. It is unknown where that burden proportionately lies within the diverse range of military occupations and how that is related to the risk of failing to return to full military duty after ACLR. There is even less known about how return to sport criteria for athletes and military members may differ or what factors are consistently associated with return to military duty. Testing done in athletes may not reflect the activities to which military members are typically exposed which result in ACL injury and reconstruction.[6] It remains unclear what is the most appropriate return to duty criteria which reflects the types of exposures in this population. There is an obvious need to assess what clinically feasible tests and measures are predictive of safe return to sport and duty after ACLR in both athletes and military members.

1.2 Specific Aims and Hypothesis

Recognizing the multifactorial nature of return to sport/duty and reinjury risk, we therefore propose a multipart study whose Specific Aims are to:

1.2.1 Specific Aim 1

Determine the effects of military occupation, sex, rank, and branch of service on the risk of ACL injury in the US military. This aim will be accomplished with a population-based epidemiological retrospective cohort study of all US military personnel over the period of 2006 to 2018 using the Defense Medical Epidemiological Database (DMED).

1.2.1.1 Hypothesis 1a

The rate of ACL injury will decline over time corresponding with the decline in operational tempo.

1.2.1.2 Hypothesis 1b

The rate of ACL injury will be higher in enlisted infantry and ground and naval gunfire officers among categories of military occupation, in the Army among branches of the military, in enlisted personnel compared to officers, and in males compared to females.

1.2.2 Specific Aim 2

Identify which performance-based and patient-reported measures of physical function have the potential to predict return to sport/duty and reinjury after ACLR using a systematic review and meta-analysis of the literature according to the Preferred Items for Systematic Review and Meta-Analyses (PRISMA) guidelines.

1.2.2.1 Hypothesis 2

Performance-based and patient-reported measures of physical function, individually or in combination as a battery of tests, will predict return to sport or duty and/or reinjury in athletes and military members after ACLR.

1.2.3 Specific Aim 3

Determine the magnitude of associations of clinically applicable performance-based and patient-reported measures of physical function as well as patient-reported psychosocial measures 6 months after ACLR with safe return to preinjury sports one year after surgery in skeletally mature athletes. The estimates of these associations will be used to inform the required sample size for larger, prospective studies.

1.2.3.1 Hypothesis 3.1

Clinically applicable performance-based and patient-reported measures of physical function as well as patient-reported psychosocial measures 6 months after ACLR will differentiate between those who **safely return to preinjury level of sport** vs. those who do not within 1 year of ACL reconstruction.

1.2.3.2 Hypothesis 3.2

Within the same candidate measures administered at 6 months, performance-based and patient-reported measures of physical function as well as patient-reported psychosocial measures will differentiate between those who **return to preinjury level of sport** vs. those who do not within 1 year of ACL reconstruction.

1.2.3.3 Hypothesis 3.3

Within the same candidate measures administered at 6 months, performance-based and patient-reported measures of physical function as well as patient-reported psychosocial measures will differentiate between those who **suffer a second ACL injury** vs. those who do not within 1 year of ACL reconstruction.

2.0 Background

2.1 Incidence of ACL injuries and Reconstruction in Athletes and Military

2.1.1 Incidence of ACL Injuries in Young Athletes

It is estimated that over 50% of high school students participate in at least one sports team[14] and almost 30% participate in club and intramural sports in college.[15] While athletic participation has many physical and social benefits,[16] the risk of injury is always present and the incidence of any particular injury depends on the sport.[17] Athletic exposures (AE) are frequently used in sports injury epidemiology to express injury rates as a function of the amount of exposure to injury where 1 AE represents 1 athlete playing in 1 game or practice.[18] A 2016 systematic review and meta-analysis found that the yearly risk of ACL injuries in high school athletes to be 0.62 injuries per 10,000 athletic exposures (AE) with basketball and soccer demonstrating the highest relative risks.[19] When considering the four-year length of a high school career, the overall risk for ACL injury can add up to be 5-10% depending on the sport.[2,19] Montalvo and colleagues performed a meta-analysis which grouped sports by level of contact and type of impact: collision sports such as football or rugby, contact sports such as basketball or soccer, limited contact sports such as baseball or volleyball, noncontact sports such as skiing or dance, and fixed-object high-impact rotational landing sports such as obstacle-course races or gymnastics. They found that the risk of ACL injury depended on the type of contact and impact and ranged from 0.25 ACL injuries per 10,000 AEs in noncontact sports to 2.62 injuries per 10,000 AEs in fixed-object high-impact rotational landing sports.[20]

Most ACL injuries in young athletes will result in surgical management. A 2013 review by Joseph and colleagues investigated ACL injuries in high school athletes in the United States and reported that 76.6% of ACL injuries resulted in surgery but the proportion who were surgically managed depended on the sport. This ranged from 54.9% in baseball to 96.3% in boys' basketball.[3] The high rate of surgery following ACL injury is not surprising given that surgical management is the favored treatment for athletes wishing to return to jumping, cutting, and pivoting sports.[21] This is in contrast to the general adult population in one area of the U.S. whose average rate of ACL reconstruction after injury was 22.6%.[22] As young athletes will receive surgical management at the highest rates to maximize the outcome of safe return to sport after ACL reconstruction, they are an important population on which to focus research efforts.

2.1.1.1 Risk of ACL Injury by Sex

When assessing risk by sex, the same 2016 review of high school athletes demonstrated that females had an overall higher rate of ACL injury with a relative risk of 1.57 (95% confidence interval (CI), 1.35-1.82) even though males had higher overall numbers of ACL injury.[19] This review found that the highest risk for ACL injury for females was seen in soccer compared to males where the highest risk was seen in football.[19] In the Montalvo review, females had significantly greater risk compared to males in both contact sports with relative risk of 3.00 (95% CI, 2.70-3.34) and in fixed-object high-impact rotational landing sports with a relative risk of 5.51 (95% CI, 2.80-10.82).[20] A review of the National Collegiate Athletic Association (NCAA) injuries also found that females sustain ACL injures at higher rates in comparable sports when contrasted with males. Within the NCAA system, 60% of ACL injures in females were by a non-contact mechanism, and in males, 59% were by a contact mechanism. The highest annual rate of injury in the NCAA for males was in football at 1.7 ACL injuries per 10,000 AEs, and for females, was in lacrosse at 2.3 ACL injuries per 10,000 AEs.[23] The evidence that sex is an important risk factor for ACL injury indicates that it should be considered in future analyses.

2.1.1.2 Risk of ACL Injury by Level of Competition and Sport

Level of competition and sport matters when it comes to ACL injury risk. Competitive adolescent athletes have been found to have over 4 times the rate of ACLR compared to non-competitive athletes.[24] When assessing the level of athlete by high school compared to college (both NCAA and club), college athletes had a significant increase in risk for a first-time noncontact ACL injury compared to high school athletes after adjusting for type of sport and sex (relative risk = 2.38, 95% CI 1.55-3.64).[25]

When categorizing sports by the level of activity, the classification as described by Hefti *et al*[26] and the version modified to include European sport activities have been frequently used.[27] Level I sports include jumping, cutting, and pivoting sports like soccer or basketball, level II includes sports with lateral movements but not the same level of pivoting such as racket sports or skiing, level III includes straight plane activities without jumping or pivoting like running or weightlifting, and level IV includes activities of daily living but no participation in sports. In a cohort of adolescent athletes, level I athletes had over 3 times the incidence of ACLR compared to level II and III sports.[24] This increased risk in level I sports was statistically significant for girls after age-adjustment.[24] It is clear that level of sport is another important factor that should be included when analyzing ACL injury risk in athletes.

2.1.2 Risk of ACL Injury in Military Members

The military is an active population and composed of many diverse occupations which have varying levels of physical requirements. Research in the U.S. Army over the period 1989-

1994 indicated that sports and physical training injuries made up 11% of all hospital admissions with an external cause of injury.[28] In the first military-wide population study assessing ACL injury, Owens and colleagues estimated the incidence of ACL injury for the International Statistical Classification of Diseases and Related Health Problems, Ninth Revision (ICD-9) codes 717.83 (old disruption of ACL) and 844.2 (sprain of knee cruciate ligament) across all services to be 2.96 per 1,000 person-years and 3.65 per 1,000 person-years, respectively, for the period of 1993 to 2003.[12] In order to compare this to ACL injury rates in athletes reported with AEs in the denominator, Moses and colleagues published a review which converted AEs to person-years to make direct comparisons of ACL injury rates. They found that in studies of at least moderate sample size, the incidence rate in professional sports ranged from 1.52 to 36.72 per 1,000 person-years, and that ACL injury in professional or elite sports are generally comparable to military groups.[29] While the incidence of ACL injury in the military is comparable to athletes, there is much less research done in this population. Based on injury data for military members, enlisted personnel are at higher risk for musculoskeletal injury compared to officers.[30-32] Occupations with high physical demands[33,34] and members of the Army[35] compared to the other service branches have previously reported higher rates of injury but there is a lack of evidence pertaining to these factors for risk of ACL injury across the military as whole. As musculoskeletal injury poses a threat to operational readiness, this group deserves further study.

2.1.2.1 Risk of ACL Injury in the Military by Sex

In a study of Naval midshipmen from 1991 to 1997, females were associated with a 2.96-fold increase in the risk of ACL injury as compared to males amongst all intercollegiate athletes, a 0.40-fold increase in the risk as compared to males amongst all intramural athletes (not statistically significant), and an 8.74-fold increase in the risk as compared to males during military training.[36] Military training activities in this study included instructional wrestling and the obstacle course, and females had almost 11 times the risk as compared to males in the obstacle course. This may be of concern since obstacle courses are common in basic training settings.[36]

When considering the U.S. military as a whole, the Owens study did not find that women had higher rates of ACL injury after controlling for age and race. They found that ICD-9 codes 717.83 (old disruption of ACL) and 844.2 (sprain of knee cruciate ligament) to be 3.09 for males and 2.29 for females per 1,000 person-years and 3.79 for males and 2.95 for females per 1,000 person-years, respectively, for the period of 1993 to 2003. Since the rescission of the "1994 Direct Ground Combat Definition and Assignment Rule" in January of 2013[37] allowed for the integration of women into all military occupations that were previously unavailable to females, an updated understanding of the incidence of ACL injury in the military by sex is needed.

2.2 Outcomes of ACL Injury and Reconstruction in Athletes and Military Members

2.2.1 Return to Activity

The goal of ACL reconstruction is to restore the knee's function and stability and enable return to activity.[38] The International Classification of Functioning, Disability, and Health (ICF) provides a common language to communicate outcomes that are meaningful to the patient and allow for comparison across studies, time, and settings.[39] In aligning research design within the ICF framework, there has been a shift from emphasis on measuring impairments in body function and structure after ACLR to defining and measuring activity limitations and participation restrictions in addition to the contextual factors that affect these outcomes.[5,10] The outcomes measured after ACLR should reflect changes in activity and participation that are meaningful to the patient.

2.2.1.1 Return to Sport Continuum

Three elements have been defined along the continuum of the outcome of return to sport. Return to participation is defined as returning to sport-specific training where the athlete may be active in their sport but at a lower level than before the injury. Return to sport means returning to preinjury level of sport but not necessarily at preinjury level of performance. Finally, return to performance is the ability to return to the athlete's sport at or above his or her preinjury level as measured by sport-specific metrics of performance.[40]

A systematic review and meta-analysis by Ardern and colleagues reported that 81% (95% CI, 74% to 87%) returned to participation in some form of sport after ACLR. Return to preinjury sport was lower at a pooled rate of 65% (95% CI, 59% to 72%). Only 55% of athletes were able to return to competitive sport after ACLR.[5] This same review reported that men were 1.5 times more likely than women to return to preinjury level of sport and 1.7 times more likely to return to competitive sport. This review also reported that additional contextual factors of younger age, playing elite sport, and positive psychological responses were favorably associated with returning to preinjury level of sport.[5] Mean time to return to sport participation has also been reported. A review found that three studies reported that the time to return to sports ranged from 6 months to 12.3 months after ACLR.[7]

Return to performance can be measured by sport-specific metrics to assess if the athlete's post-ACLR metrics have met or exceeded preinjury metrics. Sport-specific metrics are easiest to track for professional athletes, and there are examples of pre- and post-performance evaluations of professional athletes after ACLR. A study assessing NFL quarterbacks reported no statistically significant decrements in performance after ACLR using football-specific metrics such as passing yards per game, for example.[41] Another study in professional skiers using International Ski Federation (FIS) points reported, on average, skiers were able to improve beyond preinjury level of performance after ACLR.[42] These are examples where either an improvement in performance or a lack of decline in sport-specific metrics was observed. However, there are even more examples of professional athletes showing a decline in their performance. A study assessing NBA players reported a high return to sport rate of 86% after ACLR, but performance-specific metrics such as games per season and rebounds per game declined significantly from preinjury levels. This same study, however, also reported similar declines in the matched control group.[43] In the NHL, a majority of athletes also return to sport, but with a statistically significant decline in pre- to post-injury hockey-specific metrics and in comparison to matched controls.[44] A recent systematic review assessing fifteen studies on return to sport-specific performance after ACLR reported that in highly competitive athletes across multiple sports, there is a return to sport rate ranging from 63% to 97%, but the majority reported a decrease in sport-specific performance.[45]

2.2.1.1.1 Measurement of Return to Sport

Measurement of return to sport is not always reported in a consistent manner in the literature,[11] and well-defined terminology should be used according to the three elements of the continuum of return to sport. There are studies that use a binary outcome to define return to sport, such as the study by Welling and colleagues which asked, "Did you return to the pre-injury level of sport? (yes/no)."[46] However, there are also patient-reported measures which quantify activity level that have been used to measure return to sport by comparing to preinjury levels. An example of this was seen in the study by Senorski and colleagues which defined return to sport as returning to participation in knee-strenuous sport. This study used a cutoff score on the Tegner Activity

Scale, an activity scale described below, to define who returned to sport and who did not.[47] Therefore, there is a need to ensure that a consistent definition of return to sport is used, and it is also imperative that studies use validated measures to assess activity participation when using activity scales to operationally define who returns to sport and who does not.

To gauge activity participation after ACLR, several activity scales have been developed and used in the ACLR population. A systematic review from 2012 identified thirty-one rating scales from the included studies. However, only three had psychometric analysis and the rest were eliminated from discussion in the review due to inadequate development and validation. These three scales that were included in the systematic review were the Tegner Activity Scale, the Cincinnati Sports Activity Scale (CSAS), and the Marx Activity Scale.[48] These measures have been used in quantifying activity participation after ACLR by comparing to preinjury levels.[48]

The Tegner Activity Scale has been determined to be valid to document return to activity after ACL injury[49] and has acceptable properties in the ACLR population.[50] It was designed to be used with the Lysholm scale and is meant to assess change in participation over time.[48] The Tegner is scored from 0-10 with ability to participate in national/international level competitive sports rated as a 10 and inability to work/disability due to knee problems at 0. It has been routinely used in the ACLR literature to establish preinjury activity level, and it is commonly reported in articles published in high-impact orthopedic journals.[51] However, it has been described as unclear in what constitutes competitive and recreational sports participation and how individual sports are ranked on the scale.[48]

The CSAS assesses frequency of participation, and within each frequency level, scores are assigned by specific knee functions (activities with jumping and pivoting, activities with running, twisting, and turning, and activities with no running, twisting, and jumping).[52] There are a few criticisms of this scale as described in the same systematic review.[48] It is very dependent on frequency of activity over type and intensity of activity. There is ambiguity in how the data should be used such as a description of how a population is distributed on this scale or as an individual score and change in score over time. There is need for further validation and assessment of the psychometric properties of this scale.[48]

The Marx Activity Scale was developed to compare activity participation between groups and has also been used longitudinally to determine within person and within group chances in sports activity over time.[48] Scoring is based on frequency of participation by type of knee-demanding activity (running, cutting, deceleration, and pivoting). Scores range from 0-16, with 16 meaning that the individual participates in all of these activities four or more times a week. Although psychometric properties for this scale have been reported, a systematic review concluded that more validation in an ACL injured population is required.[48] This review also noted concern for a floor effect which would not distinguish between patients who stopped all sports activity and those who were still participating in sports that are less knee-demanding.[48] However, the benefits of using the Marx Activity Scale include its ease of use and generalizability in sports medicine through evaluation of clinically relevant activities rather than sport-specific questions.[53] The Marx Activity Scale has been used to quantify the level of activity and return to sport outcomes in the ACL reconstructed population.[53-57] Due to its benefits and clinical relevance regardless of sport, the Marx Activity Scale is a good choice to define activity level in the ACL injured and reconstructed population.

2.2.1.2 Return to Duty

There is much less published on return to duty rates in military members after ACLR. However, it has been reported that failure to return to duty after ACLR may be as high as 1 in 3.[6]

Within individual studies, CAPT Cullison and colleagues found that 77% of military members returned to full duty, with the most common reason for discharge cited as anterior knee pain. This study found that there were no associations of patient age, rank, time from injury to surgery, and KT-1000 measurements with the outcome of return to duty.[58] Another study assessed active duty military members after sports knee surgery (not specific to only ACLR) and found that patients with high resilience based on the Brief Resilience Scale (BRS) had much lower rates of changing military occupational specialty (MOS) at 2.3% compared to the low resilience group at 22.2%, although return to duty versus medical discharge rates were not calculated.[59] Specific to individuals undergoing ACLR, Antosh and colleagues found that 52.6% required a medical evaluation board (MEB), permanent profile, or both following surgery, and service members in noncombat roles were more likely to require either MEB or permanent profile as compared to combat arms occupations. Anterior cruciate ligament graft failure and subsequent surgeries were statistically associated with permanent profile and/or MEB.[60]

It may be possible to use the continuum of return to sport model in other populations such as military members which reflect criterion-based progression and emphasize the individual's ability to participate and return to their preinjury duties and occupation. However, this is a gap that remains in the literature regarding return to duty guidelines which focus on occupational requirements while minimizing the risk for reinjury.[6]

2.2.1.2.1 Measurement of Return to Duty

In studies assessing return to duty after ACLR in the military, it is commonly reported that military members either return to duty or they are medically discharged.[58,61] However, the outcome can be more complicated than this, such as when a military member changes military occupation after injury but remains active duty as reported in the study by Drayer and colleagues.[59]

Another circumstance that does not necessarily result in a medical discharge is when a military member has a restriction for a particular activity while still meeting military retention standards. In the Army, this is called a permanent profile, and this was one of the outcomes that was measured in military members after ACLR in the study by Antosh and colleagues.[60] Therefore, return to full duty should be given the same nuanced approach as return to sport when measuring this as an outcome. A military member may technically be considered full duty after ACLR, but if the consequences of ACLR meant there was a change in military occupation or specific long-term or permanent activity restrictions, this may be an important outcome to the military member that should be captured.

2.2.1.3 Shared Decision Making in Return to Activity

The high rates of failure to meet participation goals and sustaining a subsequent ACL injury underscore the need to better understand the return to activity decision process. This decision is not made in isolation and is the consequence of the influence by multiple stakeholders. The role of the shared decision-making process in healthcare as a whole and particularly in return to activity decisions after ACLR, is becoming widely recognized and accepted, in contrast to healthcare providers making decisions for the patient.[40,62-64] While healthcare providers, such as the sports medicine physician/surgeon and physical therapist, are the best to assess the health status and risk of further injury or complications with return to activity,[64] the patient has their own perceptions of their readiness and desires that influence their decision to return to activity.[63] The context of the activity determines the additional stakeholders who influence the return to activity decision. For example, in sports, the coach evaluates the athlete's ability to perform in a particular sport, position, and the consequences that has on other team members. With appropriate communication between all relevant stakeholders prior to return to activity, the long term outcomes associated with this decision may be maximized for the patient.[63] While there are examples of successfully integrating shared decision making after ACLR,[65] its implementation and effects on clinical practice and patient outcomes still needs to be assessed.[66,67]

2.2.2 Reinjury

Reinjury after ACLR is common, especially in young, active individuals who return to the preinjury levels of activity. One in five young athletes following ACLR will reinjure themselves after return to high-risk sports that involve jumping, cutting, and pivoting according to a recent systematic review, which was consistent with earlier findings.[7,68] The highest risk for reinjuries have been reported by multiple studies to be in the youngest group studied, typically athletes under 18, 20, or 25 as the age cutoff.[7,68-71] The same systematic review reported graft failure or reinjury to the ipsilateral side in 10% of young athletes, of which, 90% of these reinjuries occurred during high-risk sports. This occurred at a significantly higher rate in male athletes, where males had 1.64 times the odds of graft failure compared to females.[7] For ipsilateral ACL reinjuries, young male athletes have consistently shown to have higher rates over young females.[7,69,70] In the study by Webster and Feller with a mean follow up time of 5 years after ALCR, the rate of graft rupture in male athletes under 18 years of age was 28.3%![70]

Following ACLR, contralateral injury was also reported in 10% of young athletes under 20 in the systematic review by Barber-Westin & Noyes, with 80% of the injuries occurring in high-risk sports. There were no significant differences in the rates between males and females.[7] This was similar to an earlier review done which found a contralateral injury rate of 8%.[68] However, in a study by Paterno and colleagues that included athletes up to 25 years old who had a non-contact ACL injury and subsequent ACLR, the rate of overall second ACL injury was 15 times greater than control subjects, and female athletes were 6 times more likely to experience a contralateral injury compared to males.[71] It is clear that reinjury to both the ipsilateral and contralateral sides must be taken into consideration with return to sport after ACLR.

Clinical factors have been associated with reinjury in athletes after ACLR. Another study by Paterno and colleagues found that age under 19 years old, high knee related confidence, and performance on the triple hop for distance (distance relative to body height and limb symmetry index) at time of return to sport were predictors of reinjury.[72] A separate study found that athletes classified as confident as measured by responses on the KOOS-QoL subscale confidence question were over two times more likely to have a second ACL injury after return to sport. Those that were confident and met all return to sport criteria (International Knee Documentation Committee Subjective Knee Function (IKDC SKF) score at least 90 and limb symmetry indices at least 90% in strength and hop testing) were over 10 times more likely to have a second ACL injury after return to sport compared to those who met all criteria but were not classified as confident.[73]

Finally, reinjury after ACLR in the military population has not been as widely reported as it has been for athletes. A 2018 study with a majority of Army members reported a graft failure rate of 13.6% from a total of 470 participants.[60] A 2012 study estimated graft failure rates using revision ACLR surgery and found that revisions were statistically higher in active duty members at a rate of 3.8% compared to non-active duty beneficiaries at 1.8%. The authors reported that given the increased activity levels present in active-duty populations, these findings were not surprising. This study also found that younger age was associated with higher rates of revision. The authors acknowledged the potential for underestimating true graft failure rates by using rates of revision ACLR.[74] Another study exclusive to a young, highly active cohort of United States Military Academy cadets reported a graft failure rate of 16.4% out of 122 ACLR surgeries. This study also used revision surgery for the outcome of graft failure, and the authors found that the rate of failure was much higher when ACLR was performed with allografts at 44%.[75] Finally, in a long-term follow-up of at least 10 years in a study composed of 95% military members, 17.9% had graft failure. This failure rate was further broken down, and the authors reported an 8.3% failure rate in autograft reconstructions compared to 26.5% failure rate for ACLR with tibialis posterior allograft.[76] There are no studies that have been found to assess contralateral injury rates after ACLR in U.S. military members.

2.2.3 Health-Related Quality of Life

Anterior Cruciate Ligament Reconstruction should improve or restore health-related quality of life (HRQoL) after ACL injury and enable return to preinjury levels of activity. Return to activity after ACLR is not a guarantee, however, and participation restrictions after injury have a significant effect on HRQoL.[77] HRQoL after ACLR is multi-faceted. There is evidence that psychosocial factors, such as fear of reinjury, and factors related to body structures and function, such as persistent knee pain, may contribute to participation restrictions and are associated with poor HRQoL after ACLR.[78] Therefore, changes to HRQoL is an important outcome to consider after ACL injury and reconstruction.

2.2.3.1 Measurement of Health-Related Quality of Life

In a systematic review assessing health-related quality of life after ACLR, the Short Form Health Survey (SF-36), a general HRQoL measure, did not reflect changes in HRQoL after ACLR in comparison to population norms.[78] A later study, however, indicated that another non-specific measure of HRQoL, the Assessment of Quality of Life 8D Utility Instrument (AQoL-8D), showed an association with not returning to sport after ACLR with worse HRQoL as measured by the AQoL-8D.[79] Knee-specific patient reported measures that reflect knee-related quality of life, such as the Knee injury and Osteoarthritis Outcome Score-Quality of Life subscale (KOOS-QoL), are more likely to show poorer QoL values after ACLR when compared to population norms. The systematic review reported that severe radiographic osteoarthritis, post-surgical meniscal injuries, and revision ACLR were associated with poorer HRQoL after ACLR.[78]

The Anterior Cruciate Ligament Quality of Life questionnaire (ACL-QoL) is the only quality of life patient-reported measure that is specific to individuals with ACL injury. Not returning to sport was associated with poorer scores on both the ACL-QoL and KOOS-QoL patient-reported measures.[79] In patients who are symptomatic after ACLR, those with radiographic evidence of osteoarthritis have also shown worse scores on the KOOS-QoL and the ACL-QoL patient-reported measures.[80]

2.2.3.2 Post-traumatic Knee Osteoarthritis

Post-traumatic knee osteoarthritis (PTOA) is very common after ACL injury, regardless of surgical or conservative management. As this particular condition, which occurs after ACL injury, has been associated with poorer HRQoL in multiple studies, PTOA deserves mention. In a study of female soccer players with ACL injury, 51% demonstrated radiographic knee OA 12 years after surgery.[81] There were no significant differences in the prevalence of OA between those who had (56%) and had not undergone ACLR (42%). This study is close to the average long-term rate of PTOA, with reported rates after an ACL injury varying between 10% to 90% between 10 and 20 years after injury.[82] After ACLR, changes have been documented to occur as early as a year after surgery, with OA reported in all 3 compartments; one study noted medial and lateral tibiofemoral OA and patellofemoral OA in 6%, 11%, and 17% of participants, respectively at one year after

ACLR.[83] In a review of the longitudinal prevalence of PTOA after ACLR, longer postsurgical follow-up times were associated increasing proportions of PTOA; at 5, 10, and 20 years, the estimated proportions of PTOA were 11.3%, 20.6%, and 51.6%, respectively.[84] When ACL injury is combined with meniscal injury, a systematic review found that the rates of PTOA are consistently higher than without meniscal injury.[85]

Military members are found to be at an increased risk for any OA diagnosis as compared to nonexposed controls according to a systematic review.[86] Osteoarthritis has been consistently reported as a leading cause of medical discharge from the military.[87] Occupational and physical training exposures include repetitive physical demands with lifting, squatting, bending, and wearing or carrying heavy loads, and military members are also exposed to acute traumatic joint injuries at rates far above the general population.[88] Although not specific to ACL injury, one study found that the incidence of knee PTOA across US active duty service members was 0.13 per 1000 person-years, with increasing rates of both primary OA and PTOA over time.[89] Within the US Army, Cameron and colleagues estimated that soldiers are over 5 times as likely to be diagnosed with knee PTOA compared to the general population and that those with knee joint trauma while active duty were over 5 times as likely to be diagnosed with knee OA during their career.[90]

2.2.3.2.1 Measurement of Post-traumatic Knee Osteoarthritis

Since PTOA is so common after ACLR, then defining how PTOA is measured is important. As mentioned in the examples of studies reporting rates of PTOA after ACLR, radiographic OA may be reported, and this is often assessed by the Kellgren-Lawrence grading system in research.[91,92] PTOA may also be measured by magnetic resonance imaging to assess structural joint changes, which may appear before changes on radiographs.[82]

Structural joint changes found on imaging do not always equate to symptomatic knee OA. In a recent study, participants with knee symptoms after ACLR, regardless of radiographic status of knee OA, had greater knee-related QoL impairments compared to those without symptoms.[80] Symptomatic knee PTOA, which is the combination of symptomatic knee status and structural joint changes consistent with OA, may be the most meaningful definition of PTOA after ACLR as it pertains to changes in HRQoL.[82]

2.3 Factors Associated with Safe Return to Activity after ACLR

The many intrinsic and extrinsic factors that affect a safe return to activity after ACLR cover a wide range of biological, psychological, and environmental/contextual variables. Impairment-based measures have typically been employed in the clinic to assess readiness to return to sport after ACLR, but impairment-based measures alone have not been enough to predict safe return to sport.[10] Theory helps to structure what processes and domains should be modeled to conceptualize the full array of variables influencing the outcome of interest.[93] Due to the many complex and interacting variables that affect safe return to activity, an appropriate theoretical model is important for consistent and evidence-based return to activity decisions.[40]

2.3.1 Dynamic Biopsychosocial Model

The consensus statement on return to sports after injury from the First World Congress in Sports Physical Therapy stated that biopsychosocial models address all biological, psychological, and social factors that can impact treatment and outcomes that are important to return to sport.[40]

The dynamic biopsychosocial model categorizes these factors into domains that are well suited for a person's response and recovery from injury. This model incorporates four interrelated areas including cognition, affect, outcome, and behavior, and the model is dynamic to fit an individual's response to injury.[94,95] Cognition incorporates beliefs, interpretations, appraisals, and thoughts an individual has, which is where perceptions such as self-efficacy would fall. The affective response to injury includes emotions, moods, and feelings where emotions such as fear of reinjury, anxiety, and depression would fit. Behavior is described as the efforts, actions, and activities in which an individual participates. Examples include compliance with rehabilitation, exercises, and restrictions and social support or connections the individual has. The outcome domain includes the effects and consequences of the injury with the interaction of the other domains. It includes the healing process, physical and functional measures employed in the clinic, and also return to sport outcomes along the continuum.[94,95] Figure 1 depicts the dynamic biopsychosocial model that was developed by Wiese-Bjornstal *et al*.

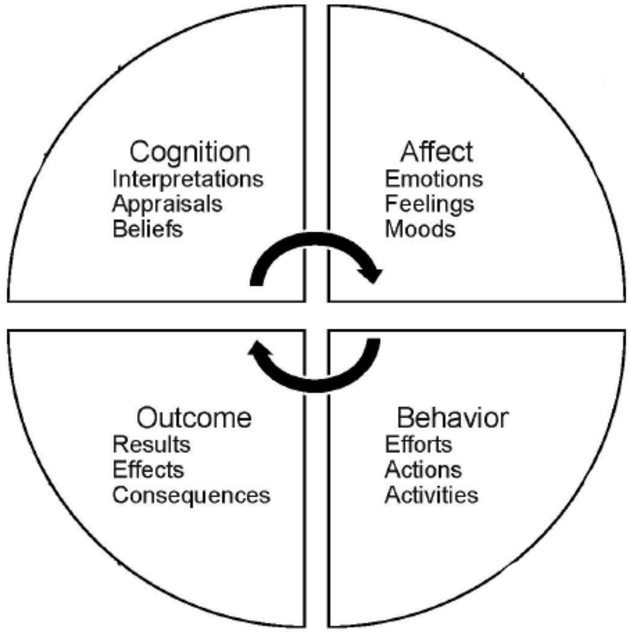

Figure 1: The Dynamic Biopsychosocial Model[95] reproduced from "Decision to Return to Sport After Anterior Cruciate Ligament Reconstruction, Part I: A Qualitative Investigation of Psychosocial Factors," Burland JP, Toonstra J, Werner JL, Mattacola CG, Howell DM, Howard JS , volume 53, page 458, copyright notice 2022 with permission from the Journal of Athletic Training

2.3.2 Haddon Matrix

It is important to not only describe the factors that affect return to activity, whether that is along the return to sport continuum, occupation, or military duty, but it is also critical to frame these factors in a way that focuses on the interventions or modifications that can be implemented to maximize outcomes and prevent reinjury. As Krieger stated "Theory, absent action, is an empty promise."[93] The Haddon Matrix is a separate framework that can serve this purpose as an action-driven framework informed by evidence. The epidemiological triad of host, agent, and environment was first expanded to injuries by Gibson when he described the agent of injury as energy that interacts with an individual within the environment, and Haddon refined this concept within the Haddon Matrix.[96,97] The Haddon Matrix has been used in injury prevention to identify the range of potential risk and protective factors associated with the epidemiological triad to guide prevention methods at the time points of pre-, during, and post-event or injury.[97,98] Environmental factors were further expanded into both the physical and sociocultural environments.[99]

Figure 2 depicts a blank Haddon matrix with the associated time points which can be completed based on the specific event or injury of interest.

	Host	Agent/Vehicle	Physical Environment	Social Environment
Pre-event				
Event				
Post-event				

Figure 2: The Haddon Matrix[99] Column and row labels reproduced from "Using the Haddon matrix: introducing the third dimension," Carol W Runyan, volume 21, page 127, copyright notice 2022 with permission from BMJ Publishing Group Ltd

In the case of ACL injury and when considering return to activity after ACLR, the agent is mechanical energy. This matrix can be repurposed to define actionable time points associated with host, agent, and environment on the timeline of return to activity. Prior to return to activity, the goal of classifying the factors of the Haddon Matrix is to improve immediate post-surgical outcomes after ACLR along the rehabilitation journey. At the time of return to activity, the goal is to facilitate a safe transition to return to activity after ACLR. After return to activity, the goal is to prevent reinjury and maximize performance outcomes within the specific activity.

2.3.3 Combined Return to Activity Theoretical Framework

The Haddon Matrix can be further modified to expand the intrinsic host factors as described by the dynamic biopsychosocial model of cognition, affect, and behavior. This proposed framework is a way to uniquely combine both the dynamic biopsychosocial model and the Haddon Matrix to encompass all relevant factors for return to activity as well as guiding actions that can be taken to maximize outcomes and prevent reinjury. To explain the combined model, an example is given for the outcome of return to sport, but this can be applied to any return to activity timeline, such as return to duty or return to occupation.

Modified Matrix for Return to Sport		Host Factors: Cognition	Host Factors: Affect	Host Factors: Behavior and Biology	Agent Factors (Energy)	Environmental Factors: Physical	Environmental Factors: Socio-Economic
Prior to RTS	Improve outcomes after ACLR by effective post-surgical interventions	Learned helplessness and self-efficacy[100] Motivation and pain perception[10] Neuro-cognitive approach to motor learning[101]	Address fear of reinjury after ACL injury and surgery in athletes[104, 105]	Medical history and concomitant injury Evidence-based rehabilitation progression and participation in neuro-muscular training[111]	Clinicians should counsel athletes about timing of RTS and associated reinjury risk[114]	Contextual interference and alterations to the physical environment in rehabilitation to prepare for sport[101]	Support system during rehabilitation[95]
Return to Sport	Facilitate safe transition to RTS after ACLR	Self-beliefs about knee function at RTS[10] Shared decision making fosters autonomy for RTS[40] Risk tolerance of the athlete[102]	Assess psychological readiness for RTS with validated measures such as the ACL-RSI[106,107]	Graft type, age, and sex factors associated with RTS[10] Effort and compliance in completing rehabilitation[112] Criterion-based RTS testing[11]	Appropriate progression once cleared to return along the continuum of practice to sport to performance[11]	Well maintained and safe environment to transition to sport	Timing of season, Financial incentives[102] Support system and the associated pressure of RTS[102,110]
Post RTS	Prevent reinjury and maximize outcomes	Levels of autonomy and motivation for adhering to injury prevention guidelines[103]	Emotional state (e.g. uncertainy, anxiety) during sport performances[108]	Practical neuro-muscular warm-up in athletes to prevent reinjury[113]	Type of sport and position influences risk of reinjury[10, 68] Sport-specific changes,such as NFL's rule change against in-game chop blocks[115]	Availability of resources: nearby or on-field medical professionals, workout facilities	Sport culture and support system[102, 110]

Figure 3: Combined Return to Activity Matrix for Return to Sport after ACLR

2.3.3.1 Host Factor: Cognition

The cognition domain is comprised of beliefs, self-appraisals, perceptions, expectations, and assumptions after injury, during rehabilitation, and after returning to activity.[95] Examples at each time point in the matrix will clarify how the matrix could be used. A clinically relevant example during the prior to return to sport timepoint includes cognitive behavioral therapies and neuropsychological modalities aimed at decreasing learned helplessness and improving self-efficacy early in rehabilitation.[100] Another example is to introduce the neurocognitive techniques to improve motor learning during rehabilitation as described by Gokeler and colleagues.[101] At the time of return to sport, self-beliefs and confidence in knee function along with the athlete's personal views on risk tolerance will affect the decision to return.[10,102] Additionally, applying the shared decision-making process at this stage is appropriate to foster autonomy.[40] After an individual has returned to activity, motivation in maintaining exercise routines and adherence to injury prevention guidelines are important for safe continued participation.[103]

2.3.3.2 Host Factor: Affect

The affect domain consists of emotions, feelings, and mood. Fear of reinjury significantly affects return to sport and may be amenable to early intervention.[10] For example, imagery training and psychologically-based interventions may improve return to activity in those with high fear of reinjury.[104,105] Assessing psychological readiness for return to sport to assist in the decision-making process should be done with a validated scale such as the Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI).[106,107] After an athlete is back in the sport, knowledge that their pre-performance emotional state may have a relationship with reinjury can be another tool to assist in long-term sports participation.[108]

2.3.3.3 Host Factor: Behavior and Biology

The behavior domain is made of the efforts, actions, and activities an individual does, and their underlying biology and healing process will affect the ability to carry out these behaviors. Nonmodifiable factors such as sex, age, concomitant injury are a few examples known to be associated with returning to activity.[10,109] Those with active coping strategies after ACLR have been associated with greater motivation, resilient behavior, higher levels of adherence to rehabilitation, lower levels of pain catastrophizing, depression, and lower levels of failing to return to sport.[110] During rehabilitation, participating in evidence-based neuromuscular training is associated with improved function without reinjury.[111] High compliance with supervised rehabilitation also improves return to sport rates after ACLR.[112] Although there is still a need to standardize return to sports testing, it is recommended to use physical examination and performance-based measures of physical function to establish recovery of the knee and assist in the return to sport decision.[11] To optimize longevity after returning to sport, evidence-based neuromuscular warm-up strategies are an example of evidence-based programs that reduce lower limb injuries during sports participation.[113]

2.3.3.4 Agent Factor: Mechanical Energy

As energy is the agent in injury, this needs to be considered at all time points surrounding return to sport. During the rehabilitation phase, clinicians should counsel athletes about expectations of the timing of return to sport and its association with reinjury. A recent cohort study found young athletes who return to sport prior to nine months post-operatively have seven times the rate of reinjury of those who delay return to sports beyond nine months.[114] To minimize excessive energy before the athlete is ready, they should be carefully progressed through return to participation, return to preinjury level of sport, and hopefully return to prior performance levels.[11] The athlete should also be aware of how their particular sport, level of sport, and position affects the risk of reinjury.[10,68] Finally, stakeholders in the return to sport decision should be aware of sport-specific rule changes to decrease the amount of mechanical energy affecting the knee such as the National Football League's chop-block rule change to decrease knee injuries.[115]

2.3.3.5 Physical Environment Factors

The physical environment should be considered prior to return to sport during the rehabilitation phase. Incorporating environmental challenges and contextual alterations into the later stages of rehabilitation to change the sensorimotor demands may better prepare the individual to return to activity.[101] At the time of return to sport, the physical environment the athlete is returning to should be considered. For example, there have been mixed findings on how playing surface affects ACL injury. One study found that in NCAA football, lower NCAA divisions demonstrated higher rates of ACL injury on turf compared to natural grass.[116] In another study, NCAA soccer players had an increased rate of ACL injury during practice on natural grass as compared to turf.[117]

2.3.3.6 Social Environmental Factors

Social factors are important to recovery after ACLR.[110] The individual's support system, starting in the rehabilitation phase, affects patient experiences and return to sport outcomes.[95] Key players in the social support system change and evolve throughout the process (family, coaches, teammates, etc.).[95] Financial incentives and level of competition, timing of the season, and pressures associated with education, career, and family are all associated with the return to sport decision.[95,102,110] Furthermore, sport culture and pressures from peers or coaches may contribute to early return to sport.[102,110]

2.3.4 Measurement of Clinically-Feasible Predictors of Safe Return to Activity

There has been a wide variation in the clinical tools, both performance-based and patient-reported, used to quantify impairments and activity limitations after ACLR. A 2011 systematic review concluded that there were few objective functional criteria used to determine when an athlete is ready to return to sport.[118] While there is recent consensus that return to sport testing should include objective, physical measures and involve specific functional skills to assess movement quality, range of motion, strength, balance, and neuromuscular control,[11] the ideal measures and time points that should be predictive of safe return to sport have not been determined. There is also consensus that contextual factors, such as psychological readiness for sport, should be considered in the return to sport decision.[11] As demonstrated through examples in the combined return to activity theoretical framework, contextual factors are important in the outcome of return to sport and reinjury. However, these have only relatively recently been recognized as important to measure and are also not standardized after ACLR.

The aim of the following sections is to provide a brief overview of patient-reported measures of function and levels of activity, patient-reported psychosocial measures, and performance-based measures of physical function that are associated with return to sport that are commonly reported in the literature.

2.3.4.1 Patient-reported Measures of Function as Predictors of Safe Return to Activity

A review of the literature assessing return to sport after ACLR demonstrated large variability in patient-reported outcomes used which creates difficulties to compare and interpret the results across studies.[51]

The **IKDC Subjective Knee Form** is the most common patient-reported measure of function used after an ACLR, and it has been reported to be used in 71% of clinical studies in high-impact journals from 2010 to 2014.[51] The components of this measure include symptoms, sports activities, and function. The IKDC Subjective Knee Form is the recommended patient-reported measure of function in the ACLR patient population based on its relevance to patients, ease of use, established measurement properties, and validation;[119] both a review of the literature on this subject and a recent consensus statement have endorsed the IKDC Subjective Knee Form in the ACLR population.[50,120] The IKDC Subjective Knee Form has been found to be predictive of return to sport in multiple studies.[9,121-124] There are other studies evaluating return to sport after ACLR that have not found an association between the IKDC Subjective Knee Form and return to sport[46] or the association disappears once other factors are included in a multivariable analysis.[125] Still, the IKDC Subjective Knee Form should be considered as a candidate predictor variable when evaluating safe return to sport after ACLR.

The **Lysholm Score** was the second most common patient-reported measure of function for individuals with ACL injury/reconstruction in the literature.[51] It consists of components related to symptoms and function of the knee but does not measure ability to participate in sports activity. Acceptable measurement properties have been reported for patients after ACL injury but with noted decrease in internal consistency when compared to other measures.[49,50] There have been a few studies which have found an association between the Lysholm Score and return to sport,[112,123] but there is concern for decreased responsiveness of this scale[126] and a high ceiling effect in the ACLR population.[127]

The **KOOS** (Knee injury and Osteoarthritis Outcome Score) includes five subscales, with three from the original Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) from which it was developed. The additional two subscales of Sport/Recreation and Quality of Life (as described earlier) incorporate patient-reported function after acute knee injuries. The subscales should be scored and interpreted independently since the original three subscales are at risk of ceiling effect in an ACL-injured population.[50,128] A study has found a univariate association between the sports and quality of life subscales and return to sport and recreational activity, although these were not significant in the study's regression analysis.[106] While its measurement properties are considered adequate, its use in an ACL-injured population has been questioned due to its number of items and lack of content validity for a young, active population with an ACL injury.[50,120,129]

The **modified version of the Cincinnati Knee Rating System** (CKRS) is the patient-reported portion that focuses on symptoms, perception of knee function, activities of daily living and sports function, and a sports activity and occupational rating scale. The original version of the CKRS with both objective and patient-reported portions has been validated in the ACLR population, but there have been inconsistencies in the version used in the literature. The modified version has not been specifically tested in this population.[50] There is a lack of evidence in the literature for an association between this scale and return to sport after ACLR.

The **Knee Numeric Entity Evaluation Score (KNEES)-ACL** is a newer measure developed for ACL-injured and reconstructed patients that covers activities of daily living, psychosocial component, knee-specific symptoms, and sports/recreation. This questionnaire has demonstrated face and content validity,[130] although more study is needed to compare to other measures used in this population.[120] Association between this scale and return to sport after ACLR has not been reported and also requires further investigation.

Preinjury levels of patient-reported activity scales have also been used to predict return to sport after ACLR.[131] Preinjury scores on the **Tegner Activity Scale** have been found to be predictive of returning to the same level of sport after ACLR.[131] The systematic review by Ardern and colleagues demonstrated that higher frequency of preinjury participation in sport-specific activity using the **Marx Activity Scale** was associated with returning to preinjury level of sport.[5] More recent studies have also found that the preinjury score on the Max Activity Scale is associated with return to preinjury sport[54] and subsequent reinjury[57] after ACLR. Ideally, patient-reported measures used after ACLR should be validated and capture relevant symptoms, impairments, activity limitations, and participation restrictions that the individual experiences after ACLR.[120] Unfortunately, there is currently no standardization for patient-reported measures of function for which measures to use after ACLR or the time points in which to utilize them. When deciding which patient-reported measures to include while designing a study assessing athletes after ACLR, the IKDC Subjective Knee Form and the Tegner or the Marx Activity Scales are recommended as potential predictors for safe return to sport based on the evidence presented here. There is a need for high-quality prospective studies to assess the prognostic value of these measures in athletes who are frequently exposed to risk in cutting and pivoting sports and in military members who return to duty and are exposed to risk in their occupation and environment.

2.3.4.2 Patient-reported Psychosocial Measures as Predictors of Safe Return to Activity

As mentioned previously in this document, psychosocial factors significantly affect return to activity after ACLR.[10] There are several common patient-reported measures used after ACLR to capture psychosocial responses that are important to the recovery process, although this is not meant to be an exhaustive list.

The **<u>Knee Self-Efficacy Scale (K-SES)</u>** has been validated in the ACLR population, is reliable, and been reported as a predictor of return to intensity and frequency of preinjury activity at one year post-operatively.[50,132] It is meant to assess knee-related self-efficacy in patients with ACL injury. Items are scored on an 11-grade Likert scale ranging from 0-10, the sum of the item scores are calculated, and then divided by the number of items, with higher scores indicating higher knee self-efficacy.[133] Patients who return to sport as determined by return to preinjury Tegner score after ACLR have higher K-SES scores compared to those who do not.[134] Furthermore, a recent systematic review and meta-analysis by Xiao and colleagues found that those who returned to sport after ACLR had significantly higher scores on the K-SES.[135] In a recent study by Piussi and colleagues, K-SES scores were significantly higher at 8- and 12-months post-ACLR in athletes that went on to suffer a graft rupture compared to those that did not.[136] Self-efficacy as captured by the K-SES in those who have undergone an ACLR shows promise as a potential important predictor of return to sport and reinjury.

The **<u>ACL-RSI scale</u>** (Anterior Cruciate Ligament Return to Sport After Injury scale) is meant to assess psychological readiness to return to sport and measures three components that includes emotions, confidence, and risk appraisal. This scale is scored on a 10 cm Visual Analog Scale with values ranging from 0 to 100, where 0 represents extremely negative psychological responses and 100 represents no negative psychological responses.[107] The short version of this scale has also been found to have good psychometric properties, and both versions have reported fair to good predictive ability in return to sport outcomes.[137] In young patients that suffered reinjury at a minimum of 2-year follow-up, the 12-month ACL-RSI scores were significantly lower compared to the non-injured group.[138] In contrast, the Piussi study found that ACL-RSI scores were significantly higher at 8- and 12-months post-ACLR in athletes that went on to have a graft rupture compared to those that did not.[136] A recent cohort study found that the ACL-RSI is predictive of return to sport at 2 years after surgery.[125] The systematic review by Xiao and colleagues found that athletes who returned to sport after ACLR had significantly higher ACL-RSI scores versus those who did not.[135] Multiple studies have established that psychological readiness should be considered when assessing the outcome of safe return to sport after ACLR.

The shortened form of the **Tampa Scale of Kinesophobia (TSK-11)** assesses fear of movement and reinjury with scores ranging from 11 to 44, where higher scores signify higher pain-related fear of movement/reinjury. The TSK-11 has been used in research with the ACLR population.[139,140] Its psychometric properties have been studied in low back pain but not in this population.[50] A recent study found that patients with greater fear with at least a score of 17 on the TSK-11 at return to sport were four times more likely to report lower levels of activity, and those with at least a score of 19 were thirteen times more likely to suffer a second ACL injury within the 24 months after return to sports.[140] Those who returned to sport had lower TSK -11 scores (less fearful) compared to those who did not in the systematic review by Xiao and colleagues.[135]

The **Multidimensional Health Locus of Control (MHLOC) scale** assesses the perceived ability to control life events, and those with high internal HLOC have a perception that personal behavior is a determinant of positive or negative life events.[141,142] The MHLOC consists of twenty-four items across four domains of internal, chance, doctors, and others. This scale has been used in the ACLR population. After ACLR, those with high internal HLOC demonstrated higher sports activity levels and were more satisfied with knee function compared to those with low internal HLOC.[141] Higher scores on the MHLOC are associated with greater psychological readiness as measured with the ACL-RSI.[143]

Finally, the **BRS** (Brief Resilience Scale) is a patient-reported psychosocial measure to capture the construct of resilience, or the ability to "bounce back" and recover from stress.[144] Most studies including the BRS and its association with return to activity have been performed in military populations, and more research is needed in civilian populations. Return to duty after ACLR was significantly influenced by pre-operative resilience.[145] After sports knee surgery in the military, service members classified as having high resilience had much lower rates of changing MOS.[59] More studies are needed to understand how resilience affects safe return to sport after ACLR.

The evidence presented here has established that psychosocial factors should be included as potential predictors when designing a study to assess safe return to sport in athletes after ACLR. The K-SES, ACL-RSI, and TSK-11 have compelling evidence for their inclusion, while the MHLOC and BRS show some promising results but require more study of their respective constructs in this population.

2.3.4.3 Performance-based Measures of Physical Function as Predictors of Safe Return to Activity

There have been a wide variety of performance-based measures of physical function used to gauge readiness for return to sport after ACLR. For the purposes of this overview, performance-based measures of physical function include measures of impaired muscle function, such as a muscle strength test, and measures to assess functional performance, such as hop tests. The following paragraphs briefly describe and discuss the prognostic value of the more common clinically feasible performance-based measures of physical function that have been reported in the literature.

Quadriceps and hamstring strength testing is frequently performed for individuals after ACLR. Isokinetic strength tests are common, and isokinetic knee extension and flexion peak torques have been done at speeds varying from 60 to 240 degrees per second.[146] Typically, limb symmetry indices (LSI) have been reported, but less frequently used metrics such as time to peak torque for flexion and extension have also been reported.[146] Measures of isometric knee flexion and extension are also common after ACLR, which can be done on an isokinetic dynamometer or with a strain gauge or hand-held dynamometer.[147] Other types of strength measurements include utilizing the 1-repetition maximum leg press test [148] and the weight-bearing single leg maximal voluntary isometric contraction (MVIC) and rate of force development measured at fixed angles using the isometric leg-press test,[149] for example, but this is not as commonly performed.[146] A systematic review investigating strength evaluation after ACLR found that there is no standardized protocol and recommended an isokinetic strength protocol test for concentric knee extension and flexion at 60 degrees per second.[150] There have been a few studies that found an association between strength measurements and return to sport rates.[151] Sousa and colleagues conducted a retrospective study and found that having less than a 15% deficit in isokinetic quadriceps and hamstring strength had a positive effect on return to sport rates.[152] In another study by Senorski and colleagues, it was found that for women, there was a significant difference in isotonic quadriceps strength between those who did compared to those who did not return to knee-strenuous sports.[134] Lentz and colleagues assessed recreational athletes after ACLR and found that quadriceps peak torque to body weight ratio was significantly higher in the group that returned to sport.[124] In amateur athletes playing ball sports, Welling and colleagues found that higher isokinetic hamstring strength was associated with a greater proportion of individuals returning to preinjury level of sports approximately two years after ACLR.[46] In a study of professional athletes, those who did not experience an ACL graft rupture after ACLR had higher ipsilateral hamstring strength and power compared to those who did experience an ACL graft rupture. Additionally, the hamstring and quadriceps peak torque ratio was found to be associated with sustaining an ACL graft rupture in athletes after ACLR.[153] It is clear from the evidence presented that strength of the thigh should be measured after ACLR as part of return to sport testing, but the parameters for testing need to be standardized.

Hop tests are another functional performance test frequently performed after ACLR that can be easily done in the clinic. The four most common hop tests include the single hop for distance, triple hop for distance, cross-over hop for distance, and the 6-meter timed hop.[154] Limb symmetry indices (LSIs) are often reported for hop tests as well, but LSI may underestimate performance deficits due to bilateral changes after surgery. Using preoperative hop distance on the uninjured leg as a reference may give a better representation of the true performance deficit,[154] but may not be practical to test immediately after an acute ACL injury. Other ways of reporting performance on the hop tests include the distance normalized to body height and absolute distance covered by the hop test in comparison to matched-controls.[72,154] Other hop tests that have been reported in the literature include the side hop, which involves medial and lateral displacement and counting the number of hops in a 30 second interval, unilateral vertical jump, unilateral repeated vertical jump, which involves jumping as fast and high as possible for 10 seconds, broad jump, countermovement jump, triple lateral hop for distance, and the 5-jump test.[146,154,155] In athletes playing level I and II sports, Nawasreh and colleagues reported that the 6-meter timed hop, triple hop and single hop LSIs measured at 6 months were predictive of return to preinjury level of sport at 12 months, and these hop tests in addition to the triple crossover hop test LSI were also predictive of return to preinjury level of sport at 24 months.[156] In another study, those with less than a 10% deficit on LSI for the vertical jump, single hop, and the triple hop were associated with higher activity levels after ACLR.[152] In a study of athletes who played competitive-level ball sports, those with a single leg hop and triple crossover hop LSI less than 85% were significantly less likely to attempt sports at 12 months after surgery as compared to those with LSI scores greater than 85%.[157] Univariate associations between the absolute scores for both the ipsilateral and contralateral legs on the single leg hop, the triple hop, and side hop measured at approximately 10 months post-operatively and return to sport measured at approximately 2 years were found by Welling and colleagues.[46] Finally, triple hop performance has been identified as part of two different risk profiles that predict second ACL injury after ACLR within 24 months of returning to sport.[72] As with strength testing, the evidence suggests that hop testing should be part of return to sport testing after ACLR. It remains unclear which specific hop tests should be done and how they should be standardized clinically.

Balance testing is another category of performance testing in the clinic which is frequently employed after ACLR. The Star Excursion and the modified Star Excursion (Y Balance) Test are examples of balance and neuromuscular control testing done in the clinic after ACLR.[158] The Biodex Balance System has been used to measure postural sway and to compare limbs.[159] The Back in Action (BIA) battery of tests is a group of seven tests developed to determine physical readiness to return to sport and has been used following ACLR. This battery consists of two stability tests, two counter-movement jump tests, a plyometric jump test, and two speed and agility tests. Double and single leg stability tests done for 20 seconds on the “MFT Challenge Disc” allows for assessment of balance and comparison to age and gender matched normative data.[160]

Although changes to balance and proprioception have been shown to persist in athletes after ACLR,[159] there is not much evidence that balance tests are predictive of return to sport. One study reported that the posterolateral Y Balance Test LSI was predictive of activity level at 2 years after ACLR.[131] With respect to reinjury after ACLR, athletes with deficits in single-leg postural stability as measured by the Biodex were twice as likely to suffer a second injury as compared to those who did not demonstrate these deficits.[161]

<u>Speed and agility</u> represent another major category of return to sports testing measures. Tests such as the quick feet test where the individual jumps in and out of two rectangles for 15 repetitions, the speedy jump test where a pre-determined hop coordination course must be completed as quickly as possible, and the plyometric jump test where the individual performs jumps as quickly as possible to maximize vertical height and minimize contact time are all part of the BIA test battery.[160] The co-contraction test assesses the ability to sidestep across a semi-circle while attached to a heavy rubber tubing for five repetitions as quickly as possible, and simulates rotational forces at the knee.[146,162] The carioca test requires the individual to move laterally with a cross-over step for 40 feet in each direction in the shortest time possible. The shuttle run test is also meant to be done as fast as possible and tests ability to change direction, accelerate, and decelerate.[146,162] The t-test is another version which combines running, changing direction, acceleration, deceleration, backwards running, and side shuffling as quickly as possible.[163]

Significant differences between those who did and did not return to preinjury level of activity have been found for the shuttle run, carioca, and co-contraction tests.[164] A more recent study in young male athletes in level I or II sports who underwent ACLR found significant differences between those that returned to previous level of sports activity and those who did not in the co-contraction and carioca tests.[162] Among the shuttle run, carioca, and co-contraction tests, the carioca test is most clinically feasible but requires more evidence for its use prior to implementing in the clinic.

Movement quality should be assessed with any functional test, however, there are tests where the quality of movement patterns are part of the assessment. Landing mechanics assessed with the Landing Error Scoring System (LESS) evaluates jump landing mechanics and scores the quality of the movement. This has been assessed in the ACLR population which found worse scores compared to controls.[165] The study by Welling and colleagues found significant differences in LESS scores between athletes that returned to preinjury level of sports and those who did not.[46] The relative amount of dynamic knee valgus assessed during the drop vertical jump (DVJ) can be reliably categorized into risk categories by trained observers and objectively measured with 2D video using knee separation ratio to approximate dynamic knee valgus.[166] Multiple biomechanical variables identified during the 3D analysis of the drop vertical jump were identified as predictive of reinjury after ACLR.[161] It should be noted specifically that increased 2D frontal plane or valgus movement, which is a more clinically feasible measure to collect, was associated with reinjury after ACLR.[161]

The functional movement screen (FMS) assesses quality of movement during seven movements and has been used less frequently after ACLR. One study used the FMS to assess effectiveness of functional movement training in an ACLR population by testing before and after the training.[167] Another found lower scores in an ACLR group compared to a control group, but additional studies would be needed to determine if using the FMS is associated with risk of reinjury and/or failure to return to sport after ACLR.[168]

There are many tests and measures which have been used in return to sport testing after ACLR, however, the best set of clinically applicable measures to predict who will be able to safely return to sport and duty still needs to be determined. This overview has found that there is a lack of standardization for both patient-reported and performance-based measures of physical function. There is variation in the study design, and there is a need for prospective cohort studies in both athletes and military members, which should specifically measure the predictor measures before the outcomes of return to activity and reinjury are assessed. For athletes, the studies included in this overview have included a wide range of sport level, in terms of competition level, the frequency of participation, and how strenuous and demanding the sports are on the knee. For those individuals who are exposed to higher levels of risk to the knee, the tests which are predictive of safe return to activity need to be identified, validated, and standardized to improve clinical outcomes after ACLR.

3.0 Sex, Military Occupation and Rank are Associated with Risk of Anterior Cruciate Ligament Injury in Tactical-Athletes

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3.1 Introduction

Anterior cruciate ligament (ACL) injury in military members (also referred to as tactical athletes) is estimated to be 10 times that of the civilian population,[12,169] which is comparable to the rate of injury in professional or elite athletes.[29] Previous epidemiological studies of ACL injury in the military population have focused on specific communities such as the US Naval Special Warfare community[34] and midshipmen at the US Naval Academy[36]; however, these groups are highly active and not representative of the typical military member. In the first military-wide population study assessing ACL injury, Owens *et al*[12] reported the incidence in the US military was 6.6 per 1000 person-years from 1993 to 2003. The burden of these injuries threaten command readiness,[6] especially during periods of increased operational requirements. Since the end of the study period investigated by Owens *et al*[12] coincided with the beginning of the conflicts Operation Enduring Freedom (OEF) in 2001 and Operation Iraqi Freedom (OIF) in 2003, an updated estimate of ACL injury incidence in the US military is needed.

Each service branch comprises an array of diverse military occupations, each of which have unique physical requirements and hazards that may influence injury rates. An overview of military occupational specialties can be viewed at https://bitly/MilOcc. Furthermore, rank may also be a factor due to changes in type and amount of exposure to potential hazards throughout a military career. While Antosh *et al*[60] investigated rank as a factor for return to duty after ACL reconstruction, there is a dearth of evidence pertaining to this as a contributing factor to ACL injuries in military tactical athletes.

Finally, rescission of the '1994 Direct Ground Combat Definition and Assignment Rule' in January 2013[37] fostered the integration of women into military occupations that were previously closed to them, such as combat arms. The Secretary of Defense issued a memorandum to direct all branches to execute their plans to fully implement women into all occupational specialties no later than 1 April 2016.[170] Since this time, it is unclear how this policy has affected the incidence of ACL injury by sex within occupational specialties. Due to changes in force composition and operational requirements, an updated assessment of the factors associated with ACL injury risk in the tactical athlete is warranted. Therefore, the aim of this epidemiological retrospective cohort study was to evaluate the effects of military occupation, sex, rank and service branch on the risk of ACL injury in the US military from 2006 to 2018.

3.2 Methods

A population-based epidemiological retrospective cohort study of all tactical athletes in the US Armed Forces was performed to assess the risk of sex, rank, service branch and military occupation on the incidence of ACL injury. The Defense Medical Epidemiological Database ((DMED), Defense Health Agency, Falls Church, Virginia, USA, https://bit.ly/DHADMEDv5) was used to identify relevant healthcare encounters. This database provides aggregated data for International Classification of Diseases (ICD)-9 and ICD-10 codes and de-identified patient characteristics, including sex, rank, categories of military occupations and service branch for all active and reserve tactical athletes. The database does not include any personal identifiable or personal health information and has been used previously for epidemiological study of lower extremity injury in the military.[12,31,171]

The database was queried for the number of distinct patients with a primary diagnosis of ACL injury (717.83 (old disruption of ACL), 844.2 (sprain of knee cruciate ligament), M23.61 (other spontaneous disruption of ACL) and S83.51 (sprain of ACL of knee)) on their initial encounter from 2006 to 2018. Individuals with repeat visits for the same diagnosis were only counted once in all analyses.

Cumulative incidence of ACL injury in male and female tactical athletes, enlisted members and officers, in each service branch (Army, Navy, Marine Corps and Air Force) and occupational category (enlisted specialties: special operations forces, mechanized/armor, artillery/gunnery, aviation, engineers, maintenance, administration, intelligence and communication, logistics and maritime/naval specialties; officer specialties: aviation, engineering and maintenance, administration, operations and intelligence, logistics and services) were calculated. Since military end strength fluctuates annually due to attrition and recruitment of replacements,[172] the population at risk was a dynamic cohort. Incidence was calculated from the sum of ACL injuries and population at risk in the 13-year study epoch. Relative risk (RR) point estimates and 95% CIs, risk difference, attributable risk (AR), number needed to harm (NNH) and $\chi 2$ statistics were calculated to assess the effects of sex and military occupational category. The preceding calculations were performed using Microsoft Excel for Mac 2016 (Microsoft, Redmond, Washington, USA).

A multivariable negative binomial regression was performed to evaluate time trends with respect to ACL injury incidence and included the factors of sex, rank and branch of service. Average marginal effects of predictor variables in the model were estimated for ease of interpretation. Due to overdispersion of the data indicated by the likelihood ratio test demonstrating that alpha is significantly different from zero, the negative binomial model was chosen over the Poisson regression model.[173] The regression analysis was performed using Stata 16 software (StataCorp, College Station, Texas, USA).

Male tactical athletes were the reference group in the assessment of sex. Enlisted personnel served the reference group for rank due to the greater disease and non-battle injuries in this group compared with commissioned officers.[30] Enlisted infantry and ground and naval gunfire officer groups were the reference in the assessment of occupational risk due to relatively higher physical requirements and organizational prioritization of these occupational categories.[31,33] Finally, the army was the reference group for service branch due to the population size and injury rates compared with the other services.[174] The level of significance was $p<0.05$ for all analyses, and no adjustments were made for multiplicity. RR point estimates were considered statistically significant if CIs did not cross 1.00.

3.3 Results

From 2006 to 2018, 59 555 enlisted male officers sustained ACL injuries (4.8 per 1000 person-years) and 8350 enlisted female officers sustained ACL injuries (3.9 per 1000 person-years) for a total of 67 905 enlisted member ACL injuries across the services (4.6 per 1000 person-years). During the same time period, 9983 male officers sustained ACL injuries (4.0 per 1000 person-years) and 2198 female officers sustained ACL injuries (4.5 per 1000 person-years) for a total of 12 181 officer ACL injuries across the services (4.1 per 1000 person-years). Tables 1 and 2 display the counts and incidence of ACL injury. Supplemental tables 1–4 (Appendix A) detail the ACL injury counts, population at risk and injury rates in male and female enlisted members and officers.

Table 1: Number and Incidence of ACL Injury among Officers in the US Armed Forces by Sex and Occupation, 2006-2018.

Officer Specialty	Ground and Naval Gunfire			Aviation			Engineering & Maintenance			Administration			Operations & Intelligence			Logistics			Services			Total		
	ACL Injuries (n)																							
	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total
Army	1110	24	1134	442	28	470	736	121	857	276	116	392	428	120	548	430	122	552	785	364	1149	4328	913	5241
Navy	388	49	437	435	37	472	279	23	302	80	23	103	151	32	183	100	12	112	351	200	551	2017	444	2461
Air Force	51	2	53	693	42	735	397	72	469	171	81	252	356	124	480	266	87	353	494	285	779	2673	742	3415
Marines	201	2	203	197	13	210	102	9	111	77	15	92	106	6	112	124	22	146	16	3	19	965	99	1064
Total	1750	77	1827	1767	120	1887	1514	225	1739	604	235	839	1041	282	1323	920	243	1163	1646	852	2498	9983	2198	12181
	Incidence (per 1000 person-years)																							
Army	4.5	7.1	4.5	4.0	4.5	4.1	4.6	4.6	4.6	4.0	4.4	4.1	4.6	6.7	4.9	4.7	4.7	4.7	3.9	4.3	4.0	4.3	4.7	4.4
Navy	3.4	3.5	3.4	3.5	4.5	3.5	3.8	5.2	3.9	3.0	3.2	3.0	4.0	5.0	4.1	3.6	2.5	3.4	3.3	3.6	3.4	3.5	3.9	3.6
Air Force	5.0	1.2	4.5	3.4	3.8	3.5	4.4	5.0	4.5	4.2	4.8	4.4	3.7	5.4	4.1	5.4	6.6	5.7	3.9	3.9	3.9	4.0	4.6	4.1
Marines	3.9	3.2	3.9	3.7	7.9	3.8	3.5	5.8	3.6	3.0	3.8	3.1	4.3	3.4	4.2	3.9	5.3	4.0	2.4	3.2	2.5	3.8	5.7	3.9
Total	4.1	3.9	4.1	3.6	4.4	3.7	4.3	4.8	4.3	3.7	4.3	3.9	4.1	5.8	4.4	4.6	5.0	4.7	3.7	3.9	3.8	4.0	4.5	4.1
Occupation Codes	O205: Ground and Naval Arms; O206: Missiles			O201: Fixed-Wing Fighter/Bomber Pilots; O202: Other Fixed-Wing Pilots; O203: Helicopter Pilots; O204: Aircraft Crews			OFF4: Engineering and Maintenance Officers			OFF1: General Officers and Executives, N.E.C.; OFF7: Administrators			O207: Operations Staff; O301: General Intelligence; O302: Communications Intelligence; O303: Counterintelligence			OFF8: Supply, Procurement and Allied Officers			OFF5: Scientists and Professionals; OFF6: Health Care Officers			All Officer Specialties		

Table 2: Number and Incidence of ACL Injury among Enlisted Members in the US Armed Forces by Sex and Occupation, 2006-2018.

Enlisted Specialty	Special Operations Forces			Infantry			Mechanized/ Armor			Artillery/Gunnery			Aviation			Engineers			Maintainance			Administration, Intelligence, & Communication			Logistics			Maritime/Naval Specialties			Total		
ACL Injuries (n)																																	
	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total	M	F	Total
Army	513	**	513	4445	**	4445	543	**	543	1474	80	1554	**	**	0	811	18	829	5957	537	6494	6097	1209	7306	3539	660	4199	29	1	30	24,634	3,406	28,040
Navy	133	**	133	60	**	60	5	**	5	139	28	167	292	24	316	**	**	**	6570	788	7358	2256	445	2701	948	173	1121	518	77	595	12,512	1,953	14,465
Air Force	**	**	**	**	**	**	**	**	**	**	**	**	264	21	285	**	**	**	5464	314	5778	3264	847	4111	1699	332	2031	**	**	**	12,177	2,252	14,429
Marines	**	**	**	1855	**	1855	180	**	180	242	**	242	97	2	99	229	14	243	3179	152	3331	2609	290	2899	1247	100	1347	**	**	**	10,232	739	10,971
Total	646	**	646	6360	**	6360	728	**	728	1855	108	1963	653	47	700	1040	32	1072	21170	1791	22961	14226	2791	17017	7433	1265	8698	547	78	625	59,555	8,350	67,905
Cumulative Incidence (per 1000 person-years)																																	
Army	6.3	**	6.3	5.5	**	5.5	5.4	**	5.4	5.8	7.1	5.8	**	**	**	5.7	5.9	5.7	5.5	5.1	5.5	5.4	3.8	5.1	6.0	5.0	5.8	5.3	1.5	4.8	5.2	4.6	5.1
Navy	5.9	**	5.9	4.5	**	4.5	3.2	**	3.2	4.0	4.7	4.1	5.2	4.4	5.1	**	**	**	4.4	3.6	4.3	4.5	2.8	4.1	4.7	3.3	4.4	4.6	2.8	4.2	4.3	3.3	4.1
Air Force	**	**	**	**	**	**	**	**	**	**	**	**	4.7	6.3	4.8	**	**	**	4.7	3.7	4.6	5.3	3.1	4.6	5.0	4.5	4.9	**	**	**	4.4	3.4	4.2
Marines	**	**	**	4.8	**	4.8	5.9	**	5.9	5.6	**	5.6	4.5	2.7	4.4	4.6	6.4	4.7	5.9	5.1	5.8	6.0	4.1	5.7	5.5	4.0	5.3	**	**	**	5.0	4.6	5.0
Total	6.2	**	6.2	5.3	**	5.3	5.5	**	5.5	5.6	6.3	5.6	4.9	4.9	4.9	5.5	6.1	5.5	4.9	4.1	4.9	5.3	3.4	4.9	5.4	4.5	5.3	4.6	2.8	4.3	4.8	3.9	4.6
Occupation Codes	E011: Special Forces			E010: Infantry, General			Occupation: E020: Armor and Amphibious, General			E041: Artillery and Gunnery; E042: Rocket Artillery; E043: Missile Artillery, Operating Crew			E050: Air Crew, General; E051: Pilots and Navigators			E030: Combat Engineering, General			ENL7: Craftsworkers; ENL1: Electronic Equipment Repairers; ENL6: Electrical/ Mechanical Equipment Repairers			ENL2: Communications and Intelligence Specialist; ENL5: Functional Support and Administration			ENL8: Service and Supply Handlers			E062: Small Boat Operators; E063: Seamanship, General; E060: Boatswains			All Enlisted Specialities		

ACL injury rates decreased over time during the study epoch (Figure 4). Male officer incidence decreased from 5.2 (95% CI: 4.9 to 5.5) to 2.7 (95% CI: 2.5 to 2.9) per 1000 person-years, female officer incidence decreased from 5.1 (95% CI: 4.3 to 5.9) to 3.7 (95% CI: 3.1 to 4.3) per 1000 person-years, enlisted male incidence decreased from 5.9 (95% CI: 5.7 to 6.1) to 3.3 (95% CI: 3.2 to 3.4) per 1000 person-years and enlisted female incidence decreased from 4.5 (95% CI: 4.2 to 4.8) to 2.8 (95% CI: 2.6 to 3.0) per 1000 person-years. Of note, the increase in incidence seen by female officers in the US Marines during 2010 and 2016 may potentially coincide with the changes in physical fitness standards for the Combat Fitness Test in the US Marine Corps. There is a plausible influence that the changes in standards may have resulted in over engagement in risk-taking activity to meet these standards.

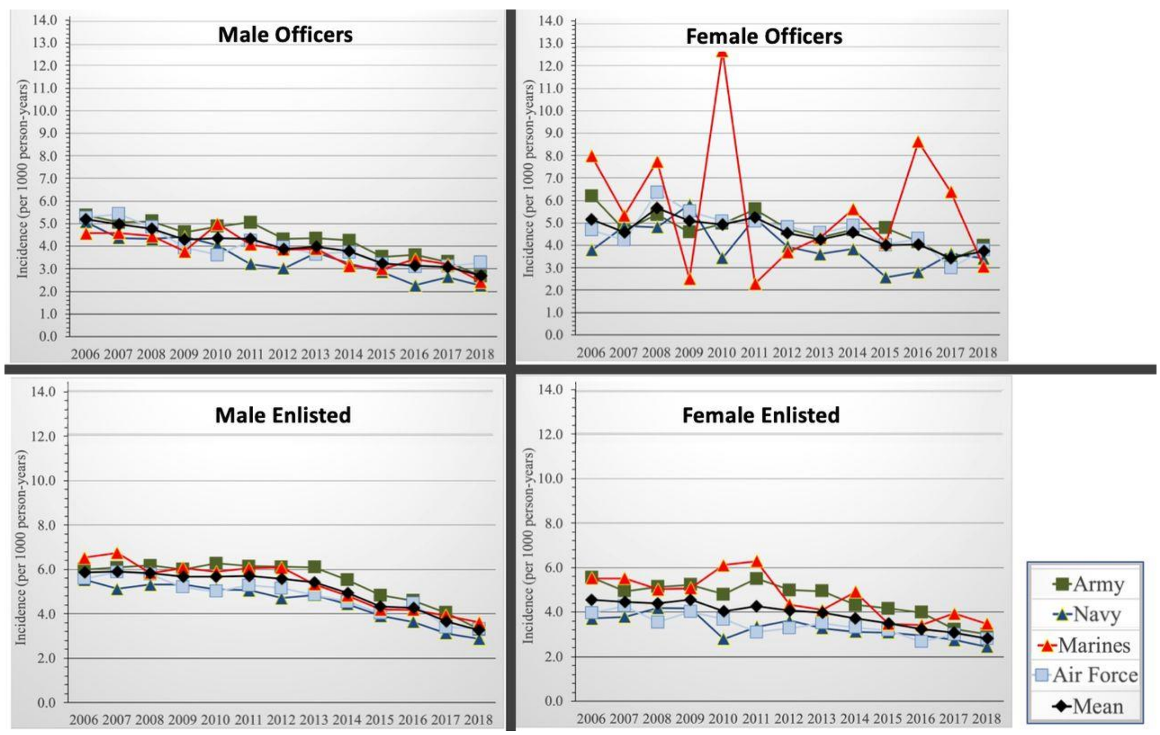


Figure 4: Anterior cruciate ligament injury incidence among male and female enlisted members and officers, US Armed Forces, 2006–2018.

Table 3 reports the risk of ACL injury by sex, with females referenced to males within their respective rank (officer vs enlisted) and occupation. The risk of ACL injury in female officers was 1.14 times that of their male colleagues (95% CI: 1.09 to 1.19; AR: 12.0%; NNH: 1836; $p<0.01$) and was greater in aviation, administration and operations and intelligence occupations (RR: 1.16–1.39; AR: 14.0%–28.1%; NNH: 617–1650; $p<0.05$) compared with male officers. The risk of ACL injury in female enlisted members was 0.82 times that of their male colleagues (95% CI: 0.80 to 0.83; AR: −22.7%; NNH: −1134; $p<0.01$) and was lower in maintenance, administration, intelligence and communication, logistics and maritime/naval specialties compared with male enlisted members (RR: 0.61–0.83; AR: −64% to −20.9%; NNH: −1173 to −523; $p<0.01$).

Results of the assessment of occupation on ACL injury risk are detailed in Table 4. Enlisted personnel in aviation, maintenance, administration, intelligence, communication and maritime/naval specialties had a 0.81–0.93 lower risk compared with infantry (AR: −23.5% to −8.0%; NNH: −2576 to −1002; $p<0.05$), and Special Operation Forces and Artillery/Gunnery occupations had a 1.07–1.19 greater risk compared with infantry (AR: 6.3%–15.8%; NNH: 1013–2827; $p<0.01$). Aviation officers and services officers had a 0.89–0.92 lower risk of ACL injury compared with ground and naval gunfire officers (AR: −12.9% to −8.2%, NNH: −2127 to −3187, $p<0.01$), and logistics officers had a 1.13 greater risk compared with ground and naval gunfire officers (AR: 11.8%; NNH: 1808, $p<0.01$).

Table 3: Risk of ACL Injury by Sex in Members of the US Armed Forces, 2006-2018.

Enlisted Specialty	Artillery/ Gunnery	Aviation	Engineers	Maintenance	Administration, Intelligence, & Communication	Logistics	Maritime/Naval Specialties	Total
RR (95% CI)	1.13 (0.93-1.37)	1.01 (0.75-1.36)	1.12 (0.79-1.58)	0.83 (0.79-0.87)	0.64 (0.61-0.37)	0.82 (0.77-0.87)	0.61 (0.48-0.77)	0.82 (0.80-0.83)
Risk difference (per 1000 person-years)	0.7	0.1	0.6	-0.9	-1.9	-1.0	-1.8	-0.9
AR (%)	11.3	1.2	10.4	-20.9	-56.2	-21.8	-64	-22.7
p	.22	.94	.54	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**
NNH	547	16600	1586	-1173	-523	-1027	-558	-1134
Officer Specialty	**Ground/ Naval Gunfire**	**Aviation**	**Engineering & Maintenance**	**Administration**	**Operations & Intelligence**	**Logistics**	**Services**	**Total**
RR (95% CI)	0.95 (0.75-1.19)	1.22 (1.01-1.47)	1.12 (0.98-1.29)	1.16 (1.00-1.35)	1.39 (1.22-1.59)	1.10 (0.96-1.27)	1.05 (0.97-1.14)	1.14 (1.09-1.19)
Risk difference (per 1000 person-years)	-0.2	0.8	0.5	0.6	1.6	0.5	0.2	0.5
AR (%)	-5.5	18.0	11.1	14	28.1	9.1	5.1	12.0
p	.64	**.03**	.10	**.05**	**<.001**	.19	.21	**<.001**
NNH	-4631	1258	1875	1650	617	2185	4924	1836

Female service members referenced to male members. RR, Relative Risk; CI, confidence interval; AR, Attributable Risk; NNH, Number Needed to Harm

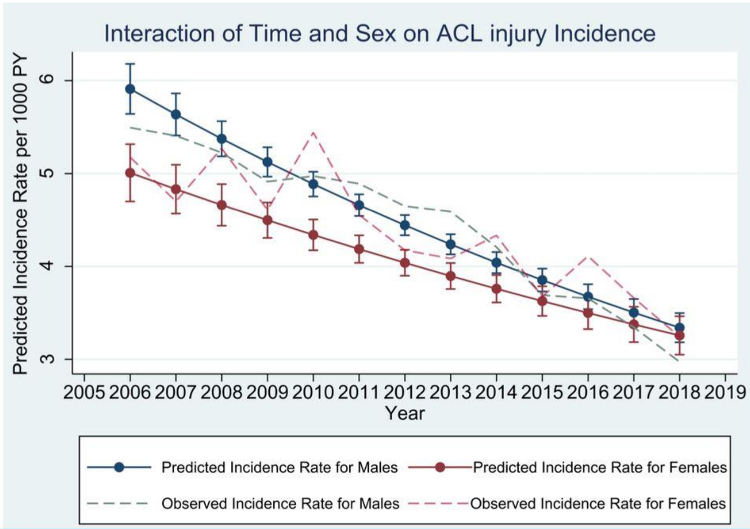
Table 4: Risk of ACL Injury by Occupation in Members of the US Armed Forces, 2006-2018

Enlisted Specialty*	Special Operation Forces	Mechanized/ Armor	Artillery/ Gunnery	Aviation	Engineers	Maintenance	Administration, Intelligence, & Communication	Logistics	Maritime/ Naval Specialties
RR (95% CI)	1.19 (1.10-1.29)	1.05 (0.97-1.13)	1.07 (1.01-1.12)	0.93 (0.86-1.00)	1.04 (0.98-1.11)	0.93 (0.90-0.95)	0.93 (0.90-0.95)	1.00 (0.97-1.04)	0.81 (0.75-0.88)
Risk difference (per 1000 person-years)	1.0	0.3	0.4	-0.4	0.2	-0.4	-0.4	0.0	-1.0
AR (%)	15.8	4.6	6.3	-8.0	3.9	-8.0	-8.0	-0.2	-23.5
p	**<.001**	.22	**.01**	**.05**	.22	**<.001**	**<.001**	.88	**<.001**
NNH	1013	3915	2827	-2576	4635	-2564	-2571	-78292	-1002
Officer Specialty†	Aviation Officers	Engineering & Maintenance	Administration	Operations & Intelligence	Logistics	Services			
RR (95% CI)	0.89 (0.83-0.94)	1.05 (0.99-1.12)	0.94 (0.87-1.02	1.07 (1.00-1.15)	1.13 (1.05-1.22)	0.92 (0.87-0.98)			
Risk difference (per 1000 person-years)	-0.5	0.2	-0.3	0.3	0.6	-0.3			
AR (%)	-12.9	5.0	-6.5	6.5	11.8	-8.2			
p	**<.001**	.12	.13	.06	**<.001**	**.01**			
NNH	-2127	4581	-3984	3479	1808	-3187			

* Contrasted to Enlisted Infantry. † Referenced to Ground and Naval Gunfire Officers. RR, Relative Risk; CI, confidence interval; AR, Attributable Risk; NNH, Number Needed to Harm

The multivariable negative binomial regression demonstrated significant effects of time, sex, an interaction effect of sex with time, rank and branch of service on the incidence of ACL injury. Through calculation of the average marginal effect, the decrease in ACL injury incidence is 0.18 cases per 1000 person-years (95% CI: 0.16 to 0.20 per 1000 person-years, $p<0.01$), after averaging over the main and interactive effects of sex, rank and branch of service. This decrease is a 4.08% relative reduction in the injury rate per year (95% CI: 3.56% to 4.60%, $p<0.01$). Officers had a 0.89 times lower rate of ACL injury (95% CI: 0.86 to 0.93, $p<0.01$) compared with enlisted personnel. The US Navy and US Air Force demonstrated 0.79 times (95% CI: 0.75 to 0.84, $p<0.01$) and 0.87 times (95% CI: 0.82 to 0.91, $p<0.01$) the rate of the US Army, respectively, while the US Marine Corps was not statistically different compared with the US Army (0.96, 95% CI: 0.91 to 1.02, $p=0.17$).

Figure 5 depicts the interaction effect of time and sex on the outcome of ACL injury incidence. Through calculation of the average marginal effect for year, a significant difference was found in the rate of decrease between males and females ($p<0.01$). The decrease in incidence in males was greater compared with females, with the difference in the rate of decrease per year at 0.069 cases per 1000 person-years (95% CI: 0.021 to 0.12, $p<0.01$).



Variable*	IRR	SE	95% CI	*p*
Year	0.954	0.00318	0.947 – 0.960	<0.001
Sex	5.50×10^{-11}	6.13×10^{-10}	1.78×10^{-20} – 0.169	0.03
Sex by Year interaction	1.012	0.00561	1.001 – 1.023	0.04
Rank	0.893	0.0187	0.858 – 0.931	<0.001
Branch of Service: USN	0.792	0.211	0.752 – 0.835	<0.001
Branch of Service: USAF	0.866	0.0227	0.823 – 0.912	<0.001
Branch of Service: USMC	0.961	0.0281	0.908 – 1.018	0.17

Figure 5: Negative binomial regression model for incident rate ratio (IRR) estimates of ACL injury over time, adjusted for sex, rank and branch of service, in members of the US Armed Forces, 2006–2018. USAF, United States Air Force; USMC, United States Marine Corps; USN, United States Navy; SE, standard error; CI, confidence interval.

3.4 Discussion

The primary finding of this study was the significant decrease in ACL injury rates over time regardless of sex, rank or branch of service, with injury rates declining at a steeper rate in male compared with female tactical athletes. The findings that ACL injury risk was modified by rank and occupation in male and female tactical athletes are the first to our knowledge to be reported.

3.4.1 Injury Rates over Time

The decrease in incidence of ACL injury likely represents a real trend with a potential contributing factor of changes in the operational tempo in the US Armed Forces over the study epoch. This could be plausibly explained by a decreased exposure to hazards with the decline of operational demands. The higher rates of ACL injury at the beginning of this study in 2006 represents a time of increased military operations with a high frequency of multiple deployments involved in OIF and OEF. Activity for these campaigns peaked in 2008,[174] and the campaigns concluded for OIF in 2011 and OEF in 2014.[175] Changes in coding may explain a small portion of this change as the ICD-10 coding transition was mandated to occur in October 2015. However, the decline in ACL injury rates occurred prior to this timepoint. While there should be a direct mapping of the codes used in this study, it is unclear how injury data for this study may have been affected.

3.4.2 Sex and Rank

Enlisted members, on average, had higher rates of ACL injury, but the risk of ACL injury by sex demonstrated an effect modification depending on rank. Female officers had a higher risk compared with male officers regardless of occupation. This was contrasted by enlisted females who demonstrated lower risk compared with enlisted males regardless of occupation. The prior population-based study by Owens *et al*[12] did not stratify by rank, which potentially masked risk differences between males and females.

The relationship between sex and rank is noteworthy when compared with what is reported in the athlete population. Accounting for the relative numbers of male and female athletes, incidence of ACL injury is higher in female athletes.[176] Furthermore, when highly active groups of tactical athletes were studied, higher incidence of ACL injury was reported in female tactical athletes.[36] It was surprising that the relative risk of ACL injury was lower in female enlisted personnel compared with their male counterparts regardless of occupation for this younger group[177] within the military. This finding, when considered with the injury reduction observed in officers, challenges the assumption that younger, physically active females are at higher risk for ACL injury.

One important difference between athletes and tactical athletes is that men and women train side by side in the US military, whereas competitive sports are stratified by sex. While tactical athletes are required to meet age-specific and sex-specific physical fitness testing standards, this is not the case regarding occupational requirements. As women increasingly enter into occupations that were previously closed to them, it is plausible that the findings of sex, rank and military occupation will likely change. Finally, it is possible that young, enlisted males are participating in activities outside of their military occupation that are increasing the risk for ACL injury in this group compared with their female counterparts.

3.4.3 Occupation and Rank

Among officers and enlisted, the risk of ACL injury varied depending on occupation. Exposures to hazards may contribute to the occupational differences observed. This study found that enlisted occupations where vehicles were primarily employed or were more sedentary in nature compared with infantry had lower risk of ACL injury. Aviation, maintenance, administration, intelligence, communication and maritime/naval specialties had significantly lower risk compared with infantry. Occupations where the knee is loaded on uneven surfaces are a known predisposing factor for ACL injury.[178] Infantry members have higher exposure to hazards that can lead to ACL injury, such as rucking, maneuvering and training over variable terrain. Similarly, aviation and services officers had a statistically lower risk of ACL injury compared with ground and naval gunfire officers.

Special Operations Forces and Artillery/Gunnery occupations were at a statistically higher risk of ACL injury compared with infantry. The highest risk of ACL injury by occupation found in this study was in the Special Operations Forces; this may be explained by the increased intensity and frequency of tactical training with a correspondingly high level of musculoskeletal injury that is known to occur in this community.[179] Occupation-specific training and physical activity levels alone are likely not the only important factors driving ACL injury. Risk-taking behaviors that are culturally influenced and vary by occupational communities are likely contributing factors as well.

3.4.4 Social Determinants

ACL injury is not typically self-limiting, and the billed medical encounters used to generate the data in this study are more likely to represent the true incidence. Due to the severity of an acute ACL injury, bias due to healthcare utilization is not likely to have a large impact on the study results. However, even with ACL injury, barriers to seeking care by tactical athletes should be considered. Fear that future career opportunities may be negatively affected is a concern that may result in under-reporting of injuries.[180] Additional reasons that may affect reporting include the service member's perception of the convenience and quality of medical care they will receive.[181] The cultural environment of the military reinforces the desire to put aside pain associated with an injury to ensure that the mission is completed and to avoid the negative perceptions associated with injury.[181] It is also plausible that under-reporting may disproportionately affect certain occupations more than others.[182]

3.4.5 Clinical and Research Implications

This study highlights important trends of ACL injury in regard to sex, occupation, rank, branch of service and changes over time. Specific hazards and exposures associated with military occupations should be explored in order to mitigate the risks. This is especially critical in communities such as Special Operations Forces, where a relatively smaller number of specialized tactical athletes must perform highly demanding physical tasks that are crucial to mission accomplishment. Surveillance of ACL injury should continue as the percentage of women in previously restricted combat roles grows. It is essential for policymakers to understand the salient factors associated with ACL injury in the military and within subpopulations, so appropriate prophylaxis and injury management can be planned. As rehabilitation specialists across the military continue to be incorporated into patient-centered medical homes and assigned to operational units, the effect on injury risk, rehabilitation and return to duty rates should be investigated.

3.4.6 Strengths and Limitations

The DMED allows for a population-based analysis which provides the best estimation of ACL injury incidence to be captured based on billed medical encounters. This permitted the calculation of sex as a non-modifiable intrinsic factor and exploration of time, rank, branch of service and military occupation as factors for ACL injury. There are also important limitations associated with this study due to inherent constraints associated with DMED. While using initial encounters allowed for the calculation of incidence, this study is also limited in the ability to capture laterality of an injury, and a new injury on the contralateral side may not be counted as such. Salient factors associated with ACL injury that have been identified in tactical athletes are unable to be measured with this database, to include factors such as medical history or body mass index. Finally, a limitation of the diagnosis code 844.2 (sprain of knee cruciate ligament) is the inclusion of posterior cruciate ligament (PCL) injuries. However, PCL injuries are relatively scarce in comparison to ACL injuries and would likely only add minimal bias to the overall results of this study.

3.5 Conclusion

Sex, rank, branch of service and military occupation have been found to be risk factors for ACL injury. There was a statistically significant decrease in the incidence of ACL injuries among tactical athletes in the US Armed Forces between the years 2006 and 2018 at an average rate of 0.18 cases per 1000 person-years or a 4.08% relative reduction each year. The rate of decrease was higher in male tactical athletes when considering rank and branch of service. The relationship of ACL injury incidence and sex was modified by rank. It is plausible that the physical demands and opportunity for exposure within specific military occupations in the enlisted and officer communities may play a role in the differences in ACL injury incidence among occupations reported in this study. Despite the decline in incidence among tactical athletes in the US military over time, the rates of ACL injury still remain higher than the civilian population.

Publication record, access information, approval, and disclaimer for this publication are listed in Appendix D.1.

4.0 Factors Associated with Return to Sport and Reinjury in Athletes and Military after Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-Analysis

4.1 Introduction

A return to sport test battery should be able to distinguish between those who will or will not be able to make a safe return to sport after ACL injury and reconstruction.[183] Rather than a discrete event, return to sport has been defined along a continuum with three elements. Return to participation is defined as returning to sport-specific training where the athlete may be active in their sport but at a lower level than before the injury. Return to sport means returning to preinjury level of sport but not necessarily at preinjury level of performance. Finally, return to performance is the ability to return to the athlete's sport at or above his or her preinjury level as measured by sport-specific metrics of performance.[40]

Neuromuscular control of the lower extremity is altered after ACLR at the time of return to sport. These changes, which include a deficit in the net hip external rotation torque during the initial phase of landing, greater asymmetry in the internal knee extensor moment, and an increase in frontal plane motion during a landing task, along with changes to postural stability, predict reinjury after return to sport.[161] These lab-based studies inform what clinical measurements should be considered for a return to sport test battery. However, these measurements often require equipment not available in the typical clinic, and therefore, would not be able to be implemented routinely.

While there are reviews that assess return to sport batteries as a whole or assess individual tests for their association with return to sport and/or reinjury,[183-186] there is not a systematic review that distinguishes the prognostic value of clinically-applicable performance-based and patient-reported measures of function in athletic and military populations for the continuum of return to sport, return to duty, and reinjury after ACLR.

Safe return to sport does not depend on physical recovery alone. The many intrinsic and extrinsic factors that affect a safe return to activity after ACLR cover a wide range of biological, psychosocial, and environmental/contextual variables.[10] Performance-based and patient-reported measures of function are the focus of this review but are one part of the larger picture. Therefore, the purpose of this study is to identify which clinically-applicable performance-based and patient-reported measures of function have the potential to predict return to sport and duty and/or reinjury after ACLR. For the purposes of this systematic review, we defined "clinically applicable performance-based measures of physical function" as those that can be reliably and accurately performed by clinicians using commonly available equipment in the clinical setting, such as isokinetic/isometric strength and hop tests. Specifically, this review seeks to answer the following questions: (1) Which clinically-applicable performance-based and patient-reported measures of function give the most prognostic information on return to participation, sport, and performance in athletes and return to duty in military personnel? (2) What tests give the most prognostic information on reinjury/graft failure rates? (3) What is the timeframe for return to sports testing that gives the most prognostic information?

4.2 Methods

This review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines,[187] and the review protocol was prospectively registered with PROSPERO (registration number CRD42021215684).

4.2.1 Information Sources

The search was developed in collaboration with a health sciences librarian (H.M.V.) with training and experience in developing systematic review searches. Ovid Medline was searched using a combination of MeSH terms and keyword searches of the title, abstract, and key word terms. The searches were adapted as appropriate for Elsevier Embase and Ebsco CINAHL and with the final search conducted on January 27, 2022. Examples of concepts searched included ACL reconstruction, return to sport/duty, reinjury, and military personnel. All search strategies are reported in Appendix B.1. After the inter-rater reliability test in DistillerSR was found to be a Kappa of 0.60, two authors independently performed study selection, first screening all titles and abstracts, then reviewing article full text; a third author (A.A.) assisted with consensus on any disagreements.

Bibliographies of relevant articles were examined for studies not found through database searches. Additionally, select relevant articles were searched to determine if they were cited by studies not found through database searches. Lastly, the names of authors of these articles were searched to ensure no studies were missed. EndNote (Clarivate) was used to store all citations found in the search process and to check for duplicates. Search results were managed using

DistillerSR[188], an online systematic review software, provided by the University of Pittsburgh Health Sciences Library.

4.2.2 Study Selection

Eligibility criteria for selection of studies were determined a priori. Studies involving athletes, aged 14 years or older, and military personnel who sustain an ACL injury and have subsequent ACLR were included. The studies must have included athletes or military members who intended to return to sport or military duty. Studies were included if they included subjects that participated level I or II sports for at least 100 hours per year. Level I sports activities included jumping, pivoting, and cutting sports such as soccer and football and Level II activities included heavy manual work, and sports like skiing, racket sports, and baseball/softball. The criterion of participation in 100 hours per year was selected to include studies with athletes that have at least one season of competitive sports participation in a year. Studies evaluating military service members were included if they included active-duty service members. Studies with participants that have concomitant injuries that significantly alter the rehabilitation progression or prognosis, such as more than a grade I injury of another knee ligament, were excluded. Meniscal and chondral pathology in the study's participants was not considered as an exclusion criterion.

To be eligible for this systematic review, studies had to meet the following study design criteria: (1) the study collected and quantitatively analyzed data on clinically applicable performance-based and/or patient-reported measures of physical function, and (2) follow-up was performed to determine ability to return to sport or duty and/or reinjury. This review evaluated quantitative, performance-based measures of physical function that could be completed with minimal equipment in the clinical setting. The patient-reported measures that were included specifically assessed the participant's perspective of their functional ability. For this systematic review, we excluded patient-reported psychosocial measures to limit the scope of the review. Studies were included if they were observational studies or randomized controlled trials. Studies were excluded if they were: (1) reviews of original research such as systematic reviews and meta-analyses and/or literature reviews, (2) case studies, commentaries, letters, posters, presentations, or editorials, (3) not published in English, or (4) not published between the years 1970 to 2022.

The outcomes that were assessed included return to military duty and/or return to sport, reinjury/graft failure to the ipsilateral or contralateral knee, and timing of return to sport testing relative to surgery timeline. Measures of association and standardized mean differences for continuous measures associated with the results of the performance-based or patient-reported measures or battery of tests for return to sport/duty and reinjury/graft failure after ACLR were calculated.

4.2.3 Risk of Bias Within Studies

The risk of bias was assessed by two independent reviewers (J.S. and A.A.) with the MINORS (Methodological Index for Non-Randomized Studies) form which is a risk-of-bias tool for non-randomized studies.[189,190] MINORS evaluates the methodological quality for both comparative and non-comparative studies.[189] Any conflicts were resolved by discussion with a third independent reviewer (J.J.I.). The MINORS assesses the following items to determine study quality: clearly stated aims, inclusion of consecutive patients, prospective collection of data, endpoints appropriate to the aim of the study, unbiased assessment of the study endpoint, follow-up period appropriate to the aim of the study, acceptable loss to follow-up, and prospective determination of the study sample size, which is scored out of 16 points for non-comparative studies. For comparative studies, additional items included adequate control group, contemporary groups, baseline equivalence of groups, and adequate statistical analyses, which is scored out of 24 points. A MINORS score lower than 70% was considered a high risk of bias, as previously reported.[191]

4.2.4 Data Analysis

4.2.4.1 Data Extraction

For those articles that were included in the systematic review, two reviewers extracted the data independently (J.S. and A.A.) with a third reviewer (J.J.I.) for consensus on any disagreements. Investigators were contacted to request data or for additional details as needed.

4.2.4.2 Data Synthesis and Statistical Analysis

Descriptive data were collected for the: (1) study population that included demographics of patient population (e.g., gender, age, race, duty status and occupation if available, type of sports in which the athletes participate) and study participant population's clinical presentation (e.g., time from surgery, additional concomitant injuries included in the study), (2) study aims/research question, (3) study design (observational, retrospective, prospective, randomized control trial), (4) sampling method (e.g. convenience sampling, random sampling), (5) total sample size, and (6) type of eligible outcome(s) included (return to sport/military duty and/or reinjury).

Data analyses were completed using Stata 17 software (StataCorp LLC, College Station, TX). For studies where only a portion of the participants were eligible for this review and the data were provided by the authors, mean differences or proportions were calculated where applicable. Effect sizes were calculated as Hedge's g for continuous data and odds ratios for proportions to standardize the comparisons between groups.[192] Random-effects meta-analyses were performed to estimate the pooled standardized mean difference (Hedge's g) and the risk estimates. Tables were used to present results of the individual studies and the forest plots were constructed to graphically display the results of the meta-analyses. Heterogeneity was investigated with the I^2 statistic to ensure that a pooled effect will provide a clinically meaningful result. For all analyses, the level of significance was $p \leq .05$.

4.3 Results

A total of 4,424 records were identified from all sources (Figure 6). Of these records 2,622 articles were screened in the title and abstract phase after duplicates were removed, 1,091 articles were assessed in the full-text phase, and 7 were included. The original search was first completed in June 2020, updated in January 2021, and the final update was in January 2022. The corresponding authors on 4 of the included articles provided additional data.[42,46,193,194]

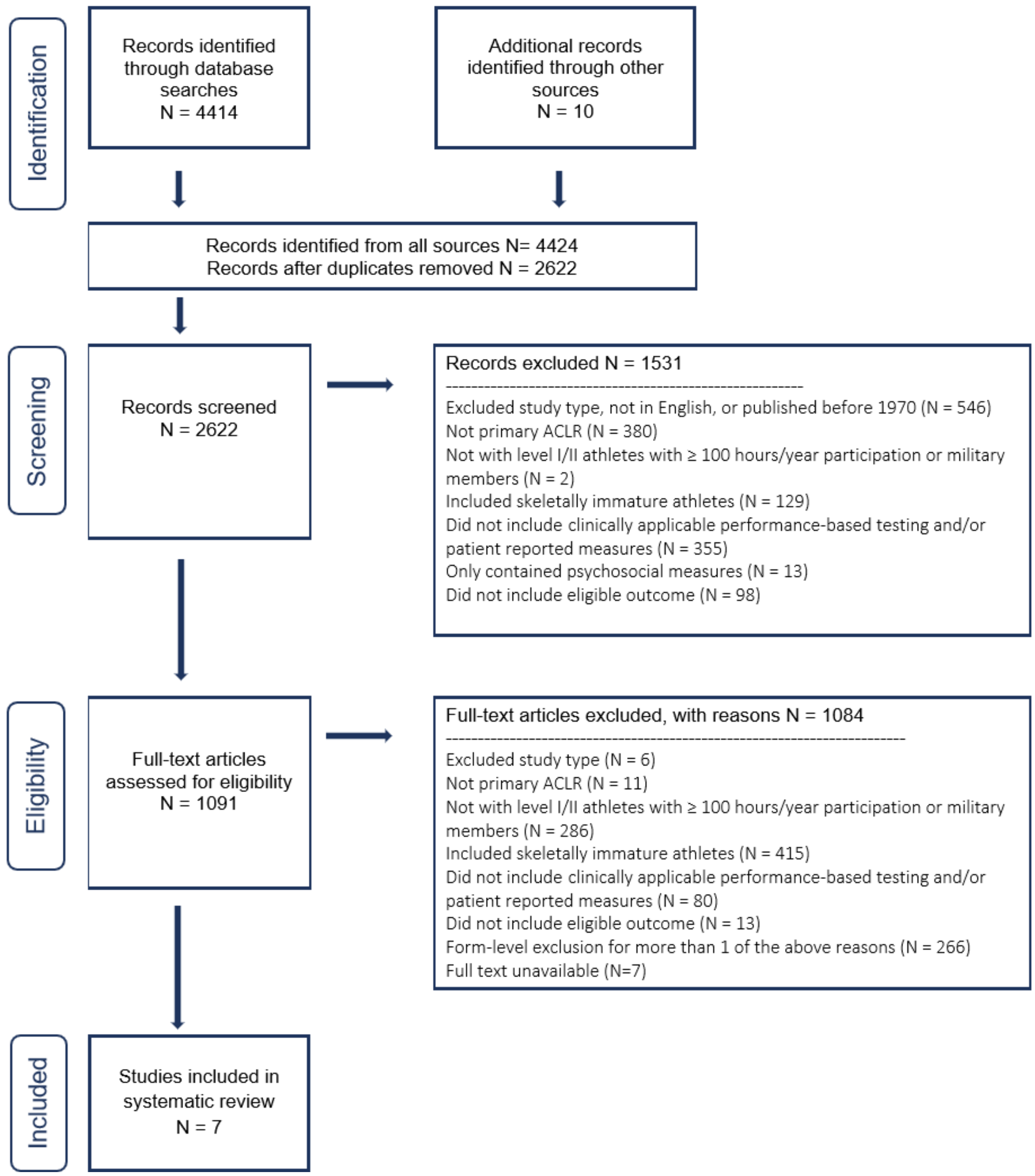


Figure 6: PRISMA Flowchart with Details

4.3.1 Study Characteristics

Of the 7 articles included, there were a variety of eligible outcomes reported and/or able to be extracted from the data. These included return to participation,[194] return to preinjury level of sport,[46,193,194] return to performance,[42] reinjury to either knee,[46,194] reinjury to the ipsilateral knee,[153,195] and injury to the contralateral knee.[196] All study populations included athletes, and there were no eligible studies with participants who were military members. Study participants included elite alpine skiers,[42] male athletes who played multi-directional field sports[195,196] or who played professional sports clubs in Qatar,[153] athletes in amateur team ball sports[46] or in a pivoting sport[194], and athletes without a restriction to the type of sport played.[193] A subset of the data was utilized for eligible participants when the study's authors provided the data for three studies where only a portion of the athletes met eligibility.[42,193,194] Study characteristics of the included articles are summarized in Table 5.

4.3.2 Risk of Bias within Studies

Five studies were classified as low risk of bias, and two were classified as high risk. The most common reasons for a lower rating were due to uncertainty about prospective calculation of study size (7 studies), unbiased assessment of the study endpoint (4 studies), and loss to follow-up greater than 5% (3 studies). Appendix B.2 displays the overall MINORS scores for the included studies.

4.3.3 Synthesis of Results

Table 6 displays the summary of results for the included studies, which includes only the eligible participants and measures for the three studies where a subset of the data was used. Appendix B.3 reports the group summary data as a comprehensive list of all eligible measures for all included studies.

Table 5: Study Characteristics

Study, year published, Country	Participant characteristics[a]	Average time (SD) from surgery to Return to Sport Testing[a]	Eligible Outcome(s) Average length of follow-up (SD) to Eligible Outcome
Retrospective cohort studies			
Csapo *et al.*[42] 2019 Austria	Elite alpine skiers N = 31 (11 males, 36%); 20.6 (3.3) years old[b] Subgroup included only participants with primary ACLR without multi-ligament injuries	5.3 (0.8) months	Return to performance in primary discipline as measured by FIS[c] points 1 year after return to competition
Kyritsis *et al.*[153] 2016 Qatar	Male professional athletes registered with sports clubs N = 158 males 21 (4) years old: No ACL graft rupture group; 22 (5) years old: ACL graft rupture group	Not listed	Reinjury to ipsilateral knee 646 days (median) after return to sport; Range 1 day to 2060 days
Welling *et al.*[46] 2020 The Netherlands	Athletes competing in amateur team ball sports ≥4 hours per week playing, age>18 years old N = 64 (44 males, 69%); 27.8 (8.8) years old 25.5 (5.8) years old in the Return to Sport group and 33.6 (12.2) years old in the Non-Return to Sport group	10.1 (1.0) months	Return to pre-injury level of sport (main outcome); reinjury to either knee 25.1 (9.9) months
Prospective cohort studies			

Ebert *et al.*[193] 2019 Australia	Athletes specifically undergoing ACLR with a hamstring autograft augmented with LARS[d] N = 34 (22 males, 65%); 22.7 (7.2) years old[b] Subgroup included only those that met activity frequency and sport type	1 year	Return to pre-injury level of sport as measured by NSARS[e] 2 years after surgery
van Melick *et al.*[194] 2022 The Netherlands	Athletes in a pivoting sport (pre-injury Tegner activity scale ≥6) age 16-50 years N = 94 (67 males, 71%), 24.5 (7.1) years old[b] Subgroup included only those athletes who completed return to sport testing	11.8 (2.9) months	Reinjury to either knee (main outcome); return to participation and pre-injury sport 17.4 (4.1) months for the main outcome of reinjury; for outcome of return to sport, the length of follow-up was 2 years
Nested case control			
King *et al.*[195] 2021 Ireland	Male athletes who played multi-directional field sports, age 18-35 years old N = 88 males matched on time from surgery to testing, time from surgery to return to play, age, and graft type	Ipsilateral reinjured group: 9.1 (3.1) months; Non-reinjured group: 9.3 (1.2) months	Reinjury to the ipsilateral knee 2 years after surgery
King *et al.*[196] 2021 Ireland	Male athletes who played multi-directional field sports, age 18-35 years old N = 115 males matched on time from surgery to testing, time from surgery to return to play, age, and graft type	Contralateral reinjury group: 9.0 (3.1) months; non-reinjured group: 9.4 (1.2) months	Reinjury to the contralateral knee 2 years after surgery

[a]Continuous measures listed as mean (standard deviation) when available, unless otherwise specified
[b]Indicates studies where only a portion of participants met the inclusion criteria but data were provided from the authors; participant characteristics were summarized for those participants whose data was utilized for this review.
[c]FIS = International Ski Federation
[d]LARS = Ligament Augmentation and Reconstruction System
[e]NSARS = Noyes Sports Activity Rating Scale

Table 6: Summary of Individual Study Results

Study	Eligible Predictor Measures Included	Outcome measured	Test Battery Pass Criteria	Summary of Results[a] Relative Risk/Odds Ratio (when available)
		Retrospective cohort studies		
Csapo *et al.*[42]	Lower extremity strength in conjunction with the "Back in Action" battery of tests, Lysholm score Tegner Activity Scale, and the Visual Analog scale for pain	Return to Performance as measured by FIS[b] points one year after return to competition in primary alpine skiing event	There were no pass/fail criteria; results were compared to age- and sex-specific normative data	No statistically significant difference between any of the measures in Return to Performance vs Non-return to Performance Groups.[a]
Kyritsis *et al.*[153]	Hop and agility testing, lower extremity strength	Reinjury (graft failure) to the ipsilateral knee	≥90% LSI[c] on isokinetic quadriceps strength at 60°/s, >90% LSI on single leg hop, triple hop, and triple crossover hop, completion of on-field sport-specific rehabilitation, and t-test <11 sec	Those who did not experience an ACL graft rupture had higher ipsilateral hamstring strength and power compared to those who did experience an ACL graft rupture. Those with a lower hamstring to quadriceps ratio at 60°/s had a greater risk of graft rupture (HR[d] 10.6 per 10% difference, (95% CI[e] 10.2-11) Those who did not meet the test battery criteria had a four times greater likelihood of sustaining a graft rupture (HR 4.1, 95% CI 1.9-9.2)
Welling *et al.*[46]	IKDC SKF[f], hop testing, lower extremity strength, movement quality of a jump landing	Return to pre-injury level of sport and reinjury to either knee	LESS[g]<5, LSI >90% for all three hops and isokinetic quadriceps and hamstring strength at 60,180, and 300°/s, quadriceps strength normalized to body weight >3.0 Nm/kg for the ipsilateral leg at 60°/s, hamstring/quadricep ratio >55% for females and >62.5% for males for the ipsilateral leg at 300°/s, ACL-RSI[h]>56 points, and IKDC SKF score	Those that returned to pre-injury level of sport had better LESS scores, higher values on the single leg hop, triple hop, and side hop on both limbs, higher hamstring strength on the ipsilateral side at 60, 180, and 300°/s and on the LSI at 60 and 180°/s compared to those that did not return to pre-injury level of sport. Passing the test battery was not associated with reinjury (no relative risk reported).

			within 15% of healthy gender- and age-matched controls	
Prospective cohort studies				
Ebert *et al.*[193]	IKDC SKF, KOOS[i], Lysholm score, Modified Cincinnati Knee Rating Score, Tegner Activity Scale, Marx Activity Scale, Physical component subscale of SF-36, Knee Outcome Survey, Global Rating of Change Scale; Lower extremity strength, hop tests, laxity measurements, and ROM[j]	Return to Pre-injury level of Sport	There were no pass/fail criteria	Statistically significant higher scores at time of testing in the Tegner and Marx Activity Scales in those that Returned to Sport vs those who did not.[a]
van Melick *et al.*[194]	Hop testing, lower extremity strength, movement quality testing	Reinjury to either knee, return to participation, and return to pre-injury level of sport	>90% LSI on quadriceps, hamstring, eccentric hamstring, and hip abduction isometric strength, >90% LSI on vertical jump, single leg hop and side hop tests, >6 on the LESS for the countermovement jump, and pass the single-leg hop-and-hold test by achieving a minimum of 90% of the length of the single leg hop with 90 degrees of knee flexion for 3 seconds	Those who <u>returned to participation</u> performed better on movement quality tests, had higher scores on hop testing on both limbs, higher values on ipsilateral quadriceps strength, bilateral hip abduction strength, and contralateral eccentric hamstring strength than those who did not. Those that <u>returned to pre-injury level of sport</u> had a higher proportion pass the single-leg hop-and-hold test and higher vertical jump values on the ipsilateral side. Those that had a <u>reinjury</u> had higher isometric hamstring strength on the contralateral side and lower isometric hip abduction LSI.[a] All nonsignificant risk of reinjury with passing: the strength battery RR[k] = 1.35 (95% CI 0.09-20.94), the hop-and-hold test RR = 0.25 (95% CI 0.17-3.87), and the movement quality battery (countermovement jump and hop-and-hold tests combined) RR = 1.24 (95% CI 0.08-19.21)[a]
Nested case control				

King *et al.*[195]	IKDC SKF and the Marx Activity Scale, lower extremity strength, hop and jump testing	Reinjury to the ipsilateral knee	≥90% LSI for quadriceps and hamstring strength, single-leg countermovement jump, single leg hop for distance, and single-leg drop jump height	Higher percentage achieving ≥90% LSI in hamstring strength in the non-reinjured group vs the reinjured group The odds of not sustaining a reinjury to the ipsilateral knee when ≥90% LSI was achieved for all tests were 0.49 (95% CI, 0.03-8.15)
King *et al.*[196]	IKDC SKF and the Marx Activity Scale, Lower extremity strength, Hop and jump testing	Injury to the contralateral knee	≥90% LSI for quadriceps and hamstring strength, single-leg countermovement jump, single leg hop for distance, and single-leg drop jump height	Lower quadriceps strength in the contralateral limb in the contralateral injured group vs the non-contralateral injured group The odds of not sustaining an injury to the contralateral knee when ≥90% LSI was achieved for all tests were 0.54 (95% CI, 0.02-16.39)

[a] = Results reported for only measures and outcomes eligible for this review.
[b]FIS= International Ski Federation
[c]LSI= Limb symmetry index
[d]HR= Hazard ratio
[e]CI= Confidence interval
[f]IKDC SKF= International Knee Documentation Committee Subjective Knee Form
[g]LESS= Landing error scoring system
[h]ACL-RSI = Anterior Cruciate Ligament- Return to Sport after Injury questionnaire
[i]KOOS = Knee injury and Osteoarthritis Outcome score
[j]ROM= Range of Motion
[k]RR= Relative risk

4.3.3.1 Return to Sport Continuum and Reinjury Results of Individual Predictor Measures

The significant findings along the return to sport continuum and reinjury outcomes are summarized in Table 7. The majority of significant findings included differences between groups based on performance of ipsilateral ACL-reconstructed and contralateral normal limbs when performing jumping/hopping and strength tests.

Table 7: Summary of Findings in Those Who Return to Play Along the Sport Continuum and Reinjury Outcomes

Eligible Predictor Measure[a]	Return to Participation	Return to Pre-injury level of Sport	Return to Performance
Landing Error Scoring System:			
Countermovement jump	↑ on the contralateral limb[194] NS[b] on the ipsilateral limb[194]	NS on either limb[194]	Not assessed
Jump Landing	Not assessed	↑[46]	Not assessed
Passing the Single-leg hop and hold test	↑ on both limbs[194]	↑ on both limbs[194]	Not assessed
Single leg hop	↑ on both limbs[194] NS for LSI[c194]	↑ on both limbs[46] NS for LSI[46,193,194] or either limb[193,194]	Not assessed
Triple hop	Not assessed	↑ on both limbs[46] NS for LSI[46,193] or either limb[193]	Not assessed
Side hop	↑ on both limbs[194] NS for LSI[194]	↑ on both limbs[46] NS for LSI[46,194] or either limb[194]	Not assessed
Vertical Jump	↑ on both limbs[194] NS for LSI[194]	↑ on the ipsilateral limb[194] NS for LSI or contralateral limb[194]	Not assessed
Isometric Quadriceps Strength	↑ on the ipsilateral limb[194] NS for LSI or contralateral limb[194]	NS for LSI or either limb[194]	Not assessed
Isometric Eccentric Hamstring Strength	↑ on the contralateral limb[194] NS for LSI or ipsilateral limb[194]	NS for LSI or either limb[194]	Not assessed
Isokinetic Hamstring Strength (60, 90, 180, and 300 deg/sec)	Not assessed	↑ on the ipsilateral limb at 60, 180, and 300 deg/sec and LSI at 60 and 180 deg/sec[46] NS for ipsilateral limb at 90 deg/sec[193], contralateral limb at any speed[46,193], or LSI at 90 and 300 deg/sec[46,193]	NS for LSI or either limb at 60 deg/sec[42]
Isometric Hip Abduction Strength	↑ on both limbs[194] NS for LSI[194]	NS for LSI or either limb[194]	Not assessed

Tegner Activity Scale	Not assessed	↑[193]	NS[42]
Marx Activity Scale	Not assessed	↑[193]	Not assessed
Eligible Predictor Measure	**No Reinjury to the Ipsilateral Limb**	**No Reinjury to the Contralateral Limb**	**No Reinjury to Either Side**
Isokinetic Quadriceps Strength (60, 180, and 300 deg/sec)	NS LSI or either limb at 60, 180, or 300 deg/sec[153,195]	↑ on the contralateral limb at 60 deg/sec[196] NS for LSI at 60 deg/sec[196]	NS for LSI or either limb at 60, 180, or 300 deg/sec[46]
Isokinetic Hamstring Strength (60, 180, and 300 deg/sec)	↑ on the ipsilateral limb at 60 and 300 deg/sec[153], ↑ ≥90% LSI at 60 deg/sec[195] NS for LSI at 180 and 300 deg/sec[153,195], on the ipsilateral side at 60[195] or 180 deg/sec[153], or on the contralateral limb at 60, 180, and 300 deg/sec[153]	NS LSI or on the contralateral side[196]	NS LSI or on either limb at 60, 180, and 300 deg/sec[46]
Isokinetic Hamstring Power (60, 180, and 300 deg/sec)	↑ on the ipsilateral limb at 60, 180, and 300 deg/sec[153] NS on the contralateral limb at 60, 180, and 300 deg/sec[153]	Not assessed	Not assessed
Isokinetic Hamstring/Quadriceps Ratio (60, 180, and 300 deg/sec)	↑ on the ipsilateral limb at 60 deg/sec[153] NS on the contralateral limb at 60 deg/sec or either limb at 180 and 300 deg/sec[153]	Not assessed	NS at 300 deg/sec[46]
Isometric Hamstring Strength	Not assessed	Not assessed	↓ on the contralateral limb[194], NS for LSI or on the ipsilateral limb[194]
Isometric Hip Abduction Strength	Not assessed	Not assessed	↑ LSI[194], NS on either limb[194]

[a]↑ indicates that those in the return to participation/sport/performance group or non-reinjured group performed better on the listed predictor measure (better score on quality assessment tests or higher values on the hop and strength tests or activity scores), and ↓ indicates a worse performance (worse score on quality assessment tests or lower values on the hop and strength tests or activity scores).
[b]NS = Non-significant finding
[c]LSI = Limb Symmetry Index

4.3.3.2 Summary of the Measures of Association

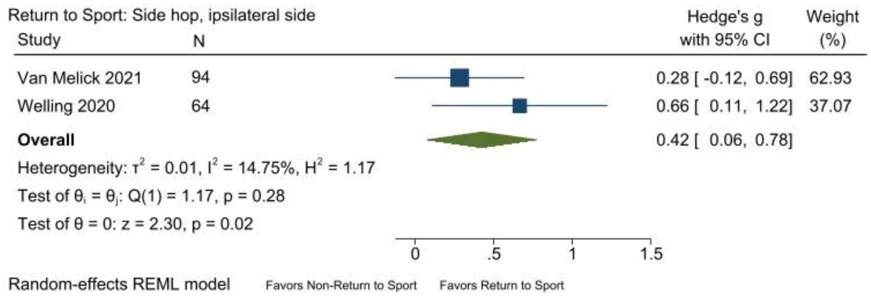
One study reported variables associated with reinjury. In the study by Kyritsis and colleagues, those with a lower hamstring to quadriceps ratio at 60˚/s had a significantly greater risk of graft rupture (Hazard ratio 10.6 per 10% difference, 95% CI 10.2-11).[153] Athletes who did not meet the test battery criteria (Table 2; ≥90% LSI on isokinetic quadriceps strength at 60˚/s, >90% LSI on single leg hop, triple hop, and triple crossover hop, completion of on-field sport-specific rehabilitation, and t-test <11 s) had a four times greater likelihood of sustaining a graft rupture (HR 4.1, 95% CI 1.9-9.2).[153]

The other studies did not find any measures significantly associated with reinjury. In both studies by King *et al.*, the odds of not sustaining a reinjury were lower but non-significant when the test battery was passed (Table 6; reinjury to the ipsilateral (ACL reconstructed) side[195] OR = 0.49 (95% confidence interval (CI), 0.03-8.15) and injury to the contralateral (non-injured) side[196] OR = 0.54 (95% CI, 0.02-16.39)). For reinjury to either knee, Welling *et al.* did not find any significant differences of the prognostic measures that they investigated between those who did versus did not have a reinjury. Furthermore, the authors reported that not passing the test battery was not predictive of reinjury.[46] In the subset of participants included in this review for the van Melick study[194], all relative risk estimates were non-significant for the risk of reinjury with passing any combination of the return to sport battery (Table 6; risk of reinjury in those who pass the strength battery: RR (relative risk) = 1.35 (95% CI 0.09-20.94), in those who pass single leg hop-and-hold test: RR = 0.25 (95% CI 0.17-3.87), and pass movement quality tests combined (single leg hop-and-hold and countermovement jump graded with the LESS): RR = 1.24 (95% CI 0.08-19.21)). As there were only two injuries in the subgroup that took return to sport tests, relative risks were not able to be calculated for the other combinations of passing the test battery reported in the van Melick study due to 0 cells in the 2 x 2 contingency tables.[194]

4.3.4 Meta-analyses Results

The results of the meta-analysis included two or three studies at most due to the limited number of articles reporting the same patient-reported or clinically-feasible performance-based measures of physical function. Figure 7 reports the only significant result of the meta-analysis for individual limb performance on the side hop for the outcome of return to sport. Figure 8 depicts the forest plots for the International Knee Documentation Committee Subjective Knee Form (IKDC SKF), and LSI measures for strength and hop testing. These were reported in the main body of the text due to interpretability, and the remaining forest plots are reported in Appendix B.4.

For return to sport, the pooled effects for the side hop for both limbs was the only significant factor that differentiated those who returned versus did not return to sport (Hedge's g, ipsilateral side 0.42 (95% CI (0.06-0.78), contralateral side 0.46 (0.13-0.78), Figure 7). The LSIs for all hop and strength tests and the IKDC SKF had non-significant pooled effect sizes for return to sports (Figure 8). For reinjury to the ipsilateral knee, the single leg hop LSI was the only measure that was pooled, but this was a non-significant effect size (Figure 8). Finally, for reinjury to either knee, the pooled effect sizes for the single leg hop and side hop for both sides along with the LSI were all non-significant (Figure 8 for LSI, Appendix B.4 for ipsilateral and contralateral sides).



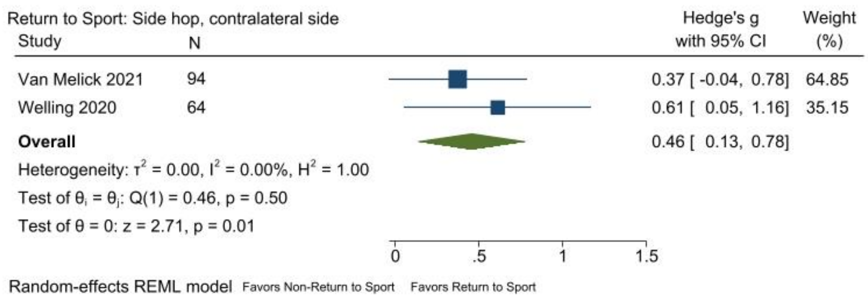
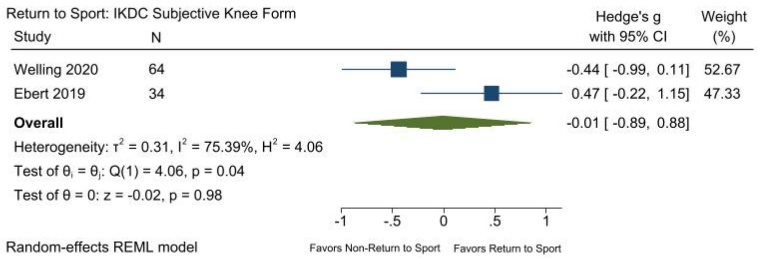
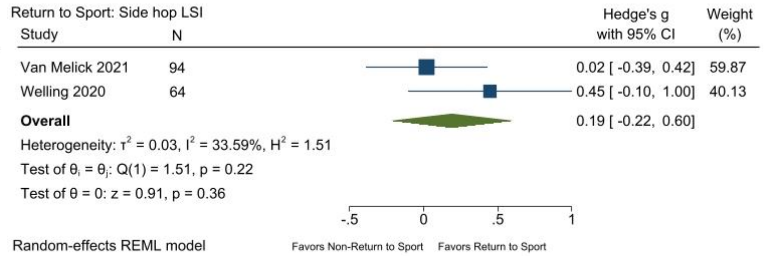
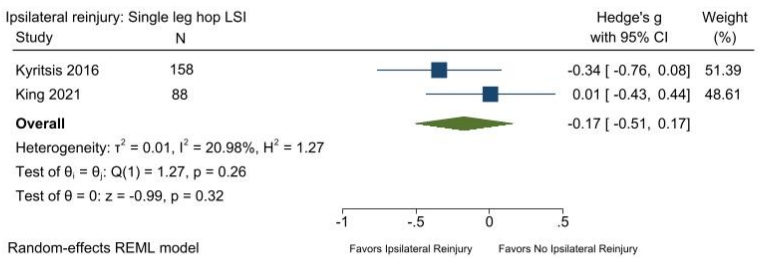
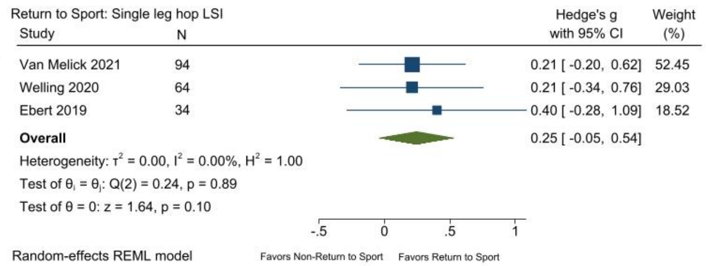


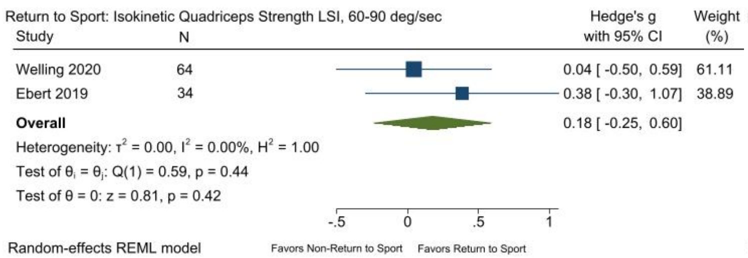
Figure 7: Forest Plots for Individual Limb Performance on the Side hop for Return to Sport

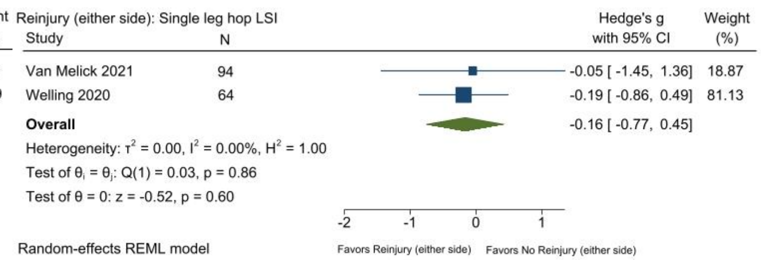

Return to Sport: IKDC Subjective Knee Form
Study N
Hedge's g with 95% CI
Weight (%)
Welling 2020 64 -0.44 [-0.99, 0.11] 52.67
Ebert 2019 34 0.47 [-0.22, 1.15] 47.33
Overall -0.01 [-0.89, 0.88]
Heterogeneity: τ² = 0.31, I² = 75.39%, H² = 4.06
Test of θi = θj: Q(1) = 4.06, p = 0.04
Test of θ = 0: z = -0.02, p = 0.98
-1 -.5 0 .5 1
Random-effects REML model
Favors Non-Return to Sport
Favors Return to Sport


Return to Sport: Side hop LSI
Study N
Hedge's g with 95% CI
Weight (%)
Van Melick 2021 94 0.02 [-0.39, 0.42] 59.87
Welling 2020 64 0.45 [-0.10, 1.00] 40.13
Overall 0.19 [-0.22, 0.60]
Heterogeneity: τ² = 0.03, I² = 33.59%, H² = 1.51
Test of θi = θj: Q(1) = 1.51, p = 0.22
Test of θ = 0: z = 0.91, p = 0.36
-.5 0 .5 1
Random-effects REML model
Favors Non-Return to Sport
Favors Return to Sport


Ipsilateral reinjury: Single leg hop LSI
Study N
Hedge's g with 95% CI
Weight (%)
Kyritsis 2016 158 -0.34 [-0.76, 0.08] 51.39
King 2021 88 0.01 [-0.43, 0.44] 48.61
Overall -0.17 [-0.51, 0.17]
Heterogeneity: τ² = 0.01, I² = 20.98%, H² = 1.27
Test of θi = θj: Q(1) = 1.27, p = 0.26
Test of θ = 0: z = -0.99, p = 0.32
-1 -.5 0 .5
Random-effects REML model
Favors Ipsilateral Reinjury
Favors No Ipsilateral Reinjury


Return to Sport: Single leg hop LSI
Study N
Hedge's g with 95% CI
Weight (%)
Van Melick 2021 94 0.21 [-0.20, 0.62] 52.45
Welling 2020 64 0.21 [-0.34, 0.76] 29.03
Ebert 2019 34 0.40 [-0.28, 1.09] 18.52
Overall 0.25 [-0.05, 0.54]
Heterogeneity: τ² = 0.00, I² = 0.00%, H² = 1.00
Test of θi = θj: Q(2) = 0.24, p = 0.89
Test of θ = 0: z = 1.64, p = 0.10
-.5 0 .5 1
Random-effects REML model
Favors Non-Return to Sport
Favors Return to Sport


Return to Sport: Isokinetic Quadriceps Strength LSI, 60-90 deg/sec
Study N
Hedge's g with 95% CI
Weight (%)
Welling 2020 64 0.04 [-0.50, 0.59] 61.11
Ebert 2019 34 0.38 [-0.30, 1.07] 38.89
Overall 0.18 [-0.25, 0.60]
Heterogeneity: τ² = 0.00, I² = 0.00%, H² = 1.00
Test of θi = θj: Q(1) = 0.59, p = 0.44
Test of θ = 0: z = 0.81, p = 0.42
-.5 0 .5 1
Random-effects REML model
Favors Non-Return to Sport
Favors Return to Sport


Reinjury (either side): Single leg hop LSI
Study N
Hedge's g with 95% CI
Weight (%)
Van Melick 2021 94 -0.05 [-1.45, 1.36] 18.87
Welling 2020 64 -0.19 [-0.86, 0.49] 81.13
Overall -0.16 [-0.77, 0.45]
Heterogeneity: τ² = 0.00, I² = 0.00%, H² = 1.00
Test of θi = θj: Q(1) = 0.03, p = 0.86
Test of θ = 0: z = -0.52, p = 0.60
-2 -1 0 1
Random-effects REML model
Favors Reinjury (either side)
Favors No Reinjury (either side)

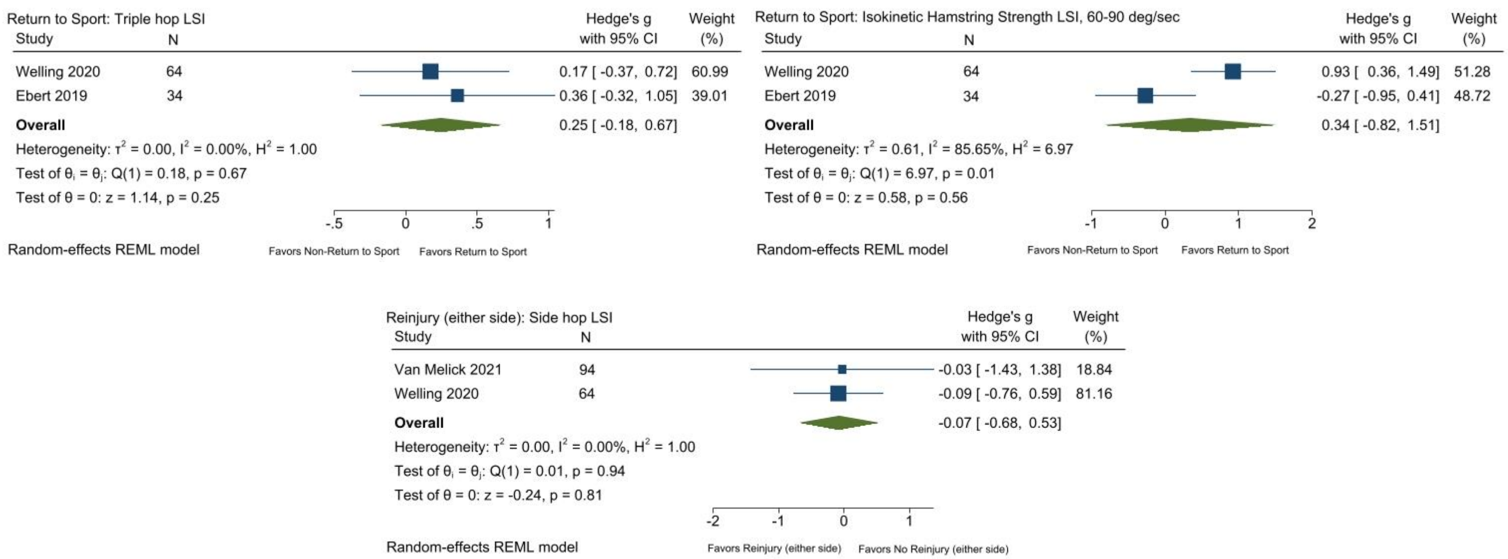


Figure 8: Forest Plots of the IKDC Subjective Knee Form and LSI for the Performance-Based Measures of Physical Function

4.4 Discussion

This systematic review and meta-analysis provide evidence of only seven studies that assess clinically-applicable measures of function to predict risk for not returning to sport and reinjury in athletes who are highly active and are at the highest risk for ACL injury. There were no studies that met the eligibility criteria in military members, despite the high incidence in this population.[197] This highlights the need for studies that assess what measures are associated with safe return to activity in high risk populations. Specifically, the eligibility criteria of this review included athletes who played I and II level sports with at least one season of sport participation per year, which was operationally defined as at least 100 hours of participation per year prior to injury. The results of this review indicate that athletes with higher levels of exposure to ACL injury and active-duty military members warrant further study.

The included studies had a variety of athlete types, measures used to test these athletes, definitions for return to sports and reinjury, and different criterion values for what consists of passing a return to sport battery. There was also variability in the timing of when return to sport testing was done after surgery; although four out of seven studies tested sometime between nine to twelve months after surgery, the limited number of studies makes it difficult to generalize about the optimal time to conduct return to sport testing. Among significant findings, lower extremity strength was a commonly reported factor differentiating reinjury groups. Strength, hop testing, movement quality assessment, and scores on activity scales differentiated those who made successful return to activity.

The results of the meta-analysis included individual limb performance and limb symmetry indices. Limb symmetry indices provide a ratio of the performance of the surgical limb compared to the non-surgical limb. They do not rely on the absolute values of the measurement of individual limbs. Limb symmetry indices assume that the contralateral limb is the "normal" control with which to compare the uninjured limb, however, research has shown that both limbs undergo strength and neuromuscular decline after ACLR.[198,199] As such, the LSI may lead to underestimation of the true performance deficit when both limbs have declined over time.

This analysis found that no included strength or hop testing LSI had a significant pooled effect size (Figure 8). This indicates that the overall effect size between groups in the population is not different than zero, with the limitation that only two or three studies were combined for any individual measure. However, for the outcome of return to preinjury level of sport, the side hop for both ipsilateral and contralateral limbs did have a significant overall small effect size (ipsilateral side: 0.42 (95% CI 0.06-0.78), contralateral side: 0.46 (95% CI 0.13-0.78), Figure 7). This result suggests that those who return to sport tend to do better as a group when assessing side hop on either the ipsilateral ACL reconstructed or contralateral normal knee, but that this is not necessarily reflected in the LSI. The side hop is distinct from the other functional measures reported in the included studies in that it is a hop test of endurance and the ability to do repetitive medial and lateral displacement. However, without normative data to interpret the strength and hop test results that is specific to age, gender, and type/frequency of activity, the use of individual limb performance is limited in its ability to determine appropriate thresholds at which an athlete should be cleared to return to sport. Future work should be directed at filling the gap of normative data for population sub-groups and assess pre-surgical contralateral limb performance to enhance the utility of both individual limb performance and LSI at the time of return to sport testing.

The pooled effect size for the IKDC SKF was also non-significant with the two studies that were combined (Figure 8). Although no other patient-reported measures were able to be combined, as a whole, athletes who returned to sport scored higher on patient-reported measures of physical function than those who did not (Appendix B.3). It is possible that variability in timing of return to sport testing and types of athletes included may play a role in why some studies found significant findings while others did not for the same measure and outcome. Additionally, for the three studies where a subset of the entire data set was used, an adequately powered study for the entire sample may no longer be considered as such when only a subset of the participant data was included.

4.4.1 Clinical Implications

Clinicians should use quantifiable measures to guide their recommendations when conducting return to sport testing after ACLR, especially those measures where differences between return to sport or reinjury groups were reported for individual studies in this systematic review. These measures included lower extremity strength, hop tests, quality assessment of jump landings, and validated patient-reported measures that include activity scales (Tegner and Marx Activity Scales). Clinicians should also be aware that individual limb performances may be masked when assessing limb symmetry indices.

4.4.2 Limitations

The limited number of studies included in this review did not allow for the planned subgroup analyses of groups based on age, competition level, and duty status which may be factors that significantly affect the rates of return to activity.[10,200] Publication bias was also not able to be formally assessed due to the limited number of studies combined for any of the pooled effect sizes, in accordance with previously published recommendations.[201] There were also multiple pooled effect sizes where the I^2 value indicated relatively high amount of heterogeneity of the effect size (6 measures with I^2 value ranging from 75-86.5%). Therefore, these pooled effect sizes should be interpreted with caution. Finally, to limit the scope of this review, psychosocial measures were not included, which represent an important component to a person's recovery and ability to safely return to sport.[202] Recent research has demonstrated the importance of the multidimensional aspect of safe return to sport after orthopedic injury, to include contextual factors like psychosocial measures.[10] Future research should involve large, prospective studies in highly active athletes and military members to comprehensively assess the best predictors of safe return to sport. Predictors should include not only patient-reported and clinically applicable performance-based measures of physical function but also psychosocial and other environmental/contextual variables. With the growing capabilities of wearable technology[203] and ability to analyze patterns within large data sets using machine-learning methodologies[204], personalized prediction of safe return to sport after ACLR may yet be a realizable goal.

4.5 Conclusion

This review found that there are limited studies assessing reinjury and the return to sport continuum after ACL reconstruction in those with the highest levels of activity and the most exposure to ACL injury. Individual studies included in this review have reported that activity level, lower extremity strength, hop tests, and movement quality may be important for safe return to sport, and the pooled analysis indicated that individual limb performance on the side hop may give an indication of who will return to preinjury level of sport. There is a high amount of variability in the type of participants, which measures are included in the return to sport testing battery, and the operational definitions of return to sports and reinjury, which indicates that much more work is required to find the best battery of tests after ACL reconstruction in this population.

4.6 Key Points

Return to sport testing in highly active individuals should include quantitative components of lower extremity strength and clinically-applicable performance-based and patient-reported measures of function. This review is unable to recommend specific, standardized measures or a battery of return to sport tests based on the current state of the evidence, although there is limited evidence regarding side hop performance for each limb is associated with return to pre-injury level of sport. The low number of studies and high heterogeneity in the meta-analyses suggest that future evidence will refine these recommendations.

4.7 Acknowledgements

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5.0 Return to Sport and Reinjury in Young Athletes after ACLR

5.1 Introduction

The percentage of those who return to their preinjury level of sport is only 65% after ACLR,[5] and the percentage of those who suffer a second ACL injury ranges from 18% to 35% in the young, active population.[7,70,73,205] This means that successful outcomes important to the patient are not reliably achieved.

There is a lack of consensus in return to sport testing and a lack of established prognostic value of the tests that are used to determine who will safely return to sport after ACLR.[11] This indicates that there is a significant proportion of variability in the outcome of safe return to sport that has yet to be accounted for in return to sport testing currently used in the clinic. It is plausible that the variability in the outcome is explained by factors beyond the current use of impairment-based testing. This unexplained variance may be represented in the Combined Return to Activity Theoretical Framework which combines the dynamic biopsychosocial model[95] and the pre-, during, and post-event time points using the epidemiological triad of the Haddon matrix.[97,99] This matrix encompasses all relevant factors for return to activity as well as guiding actions that can be taken to maximize outcomes and prevent reinjury (Figure 9). For example, psychosocial factors, such as psychological readiness to return to sport, are considered important contextual factors for individuals affected by ACL injury and reconstruction.[5] Contextual factors, which include both personal and environmental factors as defined by the International Classification of Functioning, Disease, and Health,[206] are represented within the Combined Return to Activity framework. Due to the multifactorial nature of safe return to sport after ACLR, it is imperative to not only include impairment-based measures but to also incorporate contextual factors that are important in determining this outcome.

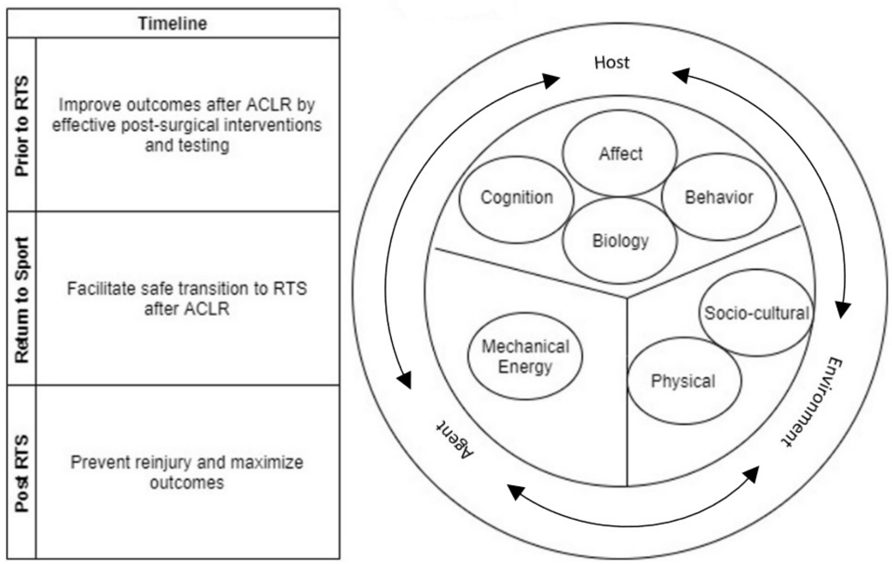


Figure 9: Summary of the Constructs modelded in the Combined Return to Activity Matrix for Return to Sport (RTS) after ACLR

Patient-centered outcomes that are clinically relevant should be captured in patients after ACLR.[120] This includes safe return to sport, which is defined as return to preinjury level of activity without reinjury to either knee. The primary purpose of this study was to determine the magnitude of associations of clinically applicable performance-based and patient-reported measures of physical function and patient-reported psychosocial measures 6 months after ACLR with safe return to preinjury sports one year after surgery in skeletally mature athletes.

5.2 Methods

5.2.1 Participants

Athletes who had sustained an ACL injury and underwent ACLR were recruited from the UPMC Freddie Fu Sports Medicine Center in Pittsburgh, Pennsylvania. All participants underwent ACLR with an extensor-mechanism autograft (quadriceps or patellar tendon) with or without lateral tenodesis. The participants returned to the clinic to complete testing at 6 months after surgery. A subset of recruited athletes was also participating in the Pittsburgh site of the ongoing multicenter STABILITY 2 Trial: ACL Reconstruction +/- Lateral Tenodesis with Patellar vs. Quad Tendon (ClinicalTrials.gov Identifier: NCT03935750). Athletes not participating in the STABILITY 2 Trial were identified during a post-operative clinical visit up to the 6-month post-operative time point after ACLR. After completing 6-month testing, athletes were followed to 12 months after surgery for the outcomes of return to preinjury level of sport and a second knee injury. This study was approved by the Institutional Review Board at the University of Pittsburgh (Study 21080014).

5.2.1.1 Inclusion and Exclusion Criteria

Inclusion Criteria:

- ACL deficient knee and planning to undergo reconstruction or has had an ACLR with a patellar or quadriceps tendon autograft and is less than 6 months from surgery.
- 14-25 years old.

- Skeletally mature (i.e. closed epiphyseal growth plates on standard of care anterior-posterior (AP) and lateral view knee radiographs).
- Two or more factors that are associated with high risk of graft failure:
    - Participate in a competitive pivoting sport (defined as sports that include cutting and pivoting activities such as basketball, American football, soccer, lacrosse, volleyball, tennis/squash, handball, downhill skiing etc); and/or
    - Have a pivot shift of grade 2 or greater when ACL deficient prior to reconstruction; and/or
    - Generalized ligamentous laxity (Beighton score of $\geq$4) and/or
    - Genu recurvatum >10 degrees.

Exclusion Criteria:

- Partial ACL rupture not undergoing an ACLR.
- Previous ACLR on either knee.
- Multiple ligament injury (two or more ligaments requiring surgery).
- Symptomatic articular cartilage defect requiring treatment other than debridement.
- >3 degrees of asymmetric varus.
- Pregnant, or
- Unable to provide consent.

All participants were planning to return to sport after cleared to do so by their surgeon and physical therapist.

5.2.2 Six-Month Testing Protocol

Participants completed the following performance-based measures of physical function and patient-reported measures at 6 months after surgery. Injury and surgical information were collected by medical record review.

5.2.2.1 Patient-Reported Data Collection

Demographic information was collected for each participant. This included age, height, weight, race and ethnicity, tobacco use, employment, daily demands, date of injury, and type of activity during which the knee was injured.

Pre-injury sport participation information included which sport or sports the individual was participating in prior to injury and the level of sport defined by the level of competition and frequency of participation. Level of sport ranged from not playing in a league or playing casually (1 or less days per week); recreational sport for beginners or social league with games or practices 1-3 days per week; competitive sport playing in a competitive league with games or practices 4-7 days per week with a coach; varsity sport playing for a high school, college, or university team with games or practices 5-7 days per week with a coach; and elite sport playing at the highest level of professional competition with games or practices 5-7 days per week.

Although the pre-injury sport participation form may be filled out as late as 6 months post-operatively in this study, there is evidence that suggests that participants can reliably recall activity patterns for the past year and several years in the past.[207,208] To determine if recall bias is an issue in this cohort, participants in the STABILITY 2 trial who had already filled out the sports participation form prior to surgery also completed this form again at 6 months after surgery to assess the level of agreement between responses.

5.2.2.1.1 Psychosocial Patient-Reported Measures

Participants completed the ACL-Return to Sport after Injury Scale (ACL-RSI), which assesses psychological readiness for return to sport with 12 items that measure emotions, confidence in performance, and risk appraisal.[107] Participants also completed the Knee Self-Efficacy Scale (K-SES). This scale assesses present and future knee self-efficacy, and the English version has been found to be a reliable and valid measure for measuring knee-specific self-efficacy for those with sport-related knee injuries.[209] Self-efficacy is defined as the perception of one's capability to perform a task.[133,210] This scale evaluates knee self-efficacy by asking participants about confidence in performing different activities in the present and confidence about knee function in the future. The Brief Resilience Scale (BRS), which assesses resilience or the ability to "bounce back" and recover from stress was also administered.[144] A single question from the Knee injury and Osteoarthritis Outcome Score (KOOS) Knee-Related Quality of Life subscale that asked "How much are you troubled with lack of confidence in your knee?" was also administered. This particular question was chosen out of the entire KOOS as a recent study identified that those who had high knee-related confidence by responding that they were never troubled with lack of confidence in their knee were over two times more likely to have a second ACL injury (OR = 2.40, 95% CI: 1.21-5.20).[73]

Social support has been identified as an important factor in enabling recovery from an injury.[211] One study by Yang and colleagues has found that collegiate athletes have increased reliance on coaches and members of their medical team, such as athletic trainers and physicians, as part of their social support networks after injury.[211] Social support networks after injury can be measured with the 6-item Social Support Questionnaire (SSQ6), which has been previously found to be reliable and valid in college students.[212] The SSQ6 directly asks social support questions such as, “Whom can you really count on to distract you from your worries when you feel under stress?”[212] As done in the study by Yang and colleagues, the questionnaire uses response choices to represent different sources of social support to the athlete, such as family, friends, their coach, and different members of the medical team.[211] Participants in the current study completed the SSQ6. Scoring of the SSQ6 involves two parts, in which the average number of different sources of social support is calculated for the six questions and the athlete’s average amount of satisfaction with each source of social support is calculated as measured by a 6-point Likert scale.[212]

5.2.2.1.2 Patient-Reported Measures of Function

Participants completed two patient-reported measures of function: the International Knee Documentation Committee Subjective Knee Form (IKDC SKF) and the Marx Activity Scale. The IKDC SKF is an 18-item measure that assesses symptoms, function, and sports activity with higher scores indicating higher levels of function and activity.[113] The Marx Activity Scale assesses frequency of specific sports activities (running, cutting, decelerating, and pivoting)[213] and was modified to ask about activity over the last month as it was administered at the 6-month post-operative time point.

5.2.2.2 Performance-based Measures of Physical Function

5.2.2.2.1 Isokinetic Quadriceps and Hamstring Strength

Peak torque, average power, and average peak torque for 3 repetitions for knee extension and flexion at 90 degrees per second was recorded for the involved and non-involved knee. Using the average peak torque values, the hamstring and quadriceps peak torque ratio was also calculated.

5.2.2.2.2 Hop Testing

The single hop for distance, straight triple hop for distance, triple cross-over hop for distance, timed 6-meter hop, and the side hop were performed in accordance with methods reported in the literature.[214,215] The average of two trials for each limb was calculated for the hop tests except for the side hop, which was performed once on each limb. The limb symmetry index (LSI) was calculated for each hop test. Distance relative to body height and the LSI for the triple hop for distance are part of two high-risk profiles in young athletes who have had an ACLR used to identify those at high risk of sustaining a second ACL injury after return to sport.[72] For this reason, the distance relative to body height was an additional metric calculated for the triple hop for distance.

5.2.2.2.3 Drop Vertical Jump

Frontal plane movement was assessed during the drop vertical jump test using the Microsoft Kinect V2 and the ACL-Gold software. The ratio of the distance between the knees to the distance between the ankles was determined and defined as a measure of dynamic valgus of the lower extremity. The average value of dynamic valgus of the lower extremity for 3 drop vertical jumps was calculated for each participant.

5.2.2.2.4 Carioca Test

The carioca test is a functional performance test which requires lateral movement with a cross-over step for 40 ft in each direction. The test was completed in the shortest time possible.[164]

5.2.2.2.5 Plyometric Jump

The double-leg plyometric jump is part of the Back in Action test battery and consists of three consecutive jumps with a focus to maximize jump height and minimize ground contact time.[160,216] The reactive strength index can be calculated for this jump by dividing the jump height by contact time.[42] Air flight time and contact time was recorded using the MuscleLab® (Ergotest Technology, Oslo, Norway). This device uses an infrared light beam 4mm above the floor connected to a timer that is triggered by the interruption in the beam, as has been done in a previous study.[217] Jump height was then calculated by the system,[217] and the reactive strength index was recorded for the average of three consecutive jumps. This method of conducting the plyometric jump has good test-retest reliability as reported by the intra-class correlation coefficient (0.83-0.94).[217] The average values for the double-leg and single-leg plyometric jumps for both sides were recorded.

5.2.3 Athletic Exposures

Participants' exposure to sport activity was monitored from the 6 to 12-month period by survey that collected information about any sport activity over the previous month, the reason why not if applicable, and what sport(s) and number of practices and games for each sport they reported. All sport activity information was collected, from level I jumping, cutting, and pivoting sports to level III straight-plane activities such as swimming.[26] Participants also reported if they had an injury that required them to miss more than one day from any sport over the previous month. Each game or practice session was recorded as the number of athletic exposures (AE),[218] and the total cumulative exposures for the month was recorded. Every effort was made to collect this information, and data collected outside of the window (> 1 week after the 1-month deadline) was still recorded but noted as an estimate of AEs for the month.

5.2.4 One Year Outcome of Safe Return to Sport

The outcome of safe return to preinjury level of sport was assessed one year after ACLR when the participant reported that they returned to preinjury or higher level of their primary sport without a reinjury to the ipsilateral or contralateral knee at 1 year. Return to sport and reinjury were also assessed separately as secondary outcomes.

Return to preinjury level of sport was determined by asking if the participant has returned to the preinjury sport(s) listed on the Sports Participation Form, if the participant has returned to full or partial participation, and if the participant has returned to the same, higher, or lower level of sport as defined on the Sport Participation Form. The criteria for return to preinjury level of sport was met when the participant reported that they have returned to their primary sport at the same or higher level on the Return to Sport Form.

Participants were asked if they sustained a second knee injury with the response of yes or no answer to determine if the participant had a reinjury. If yes, the participant indicated if the injury was to the same knee or to the opposite knee to determine if it was an injury to the ipsilateral or contralateral side.

5.2.5 Statistical Analysis

Descriptive statistics for the demographic data and the 6-month clinical measures were reported as proportions and counts for categorical variables. For continuous variables, the mean and standard deviation were reported when the distribution appeared symmetric on a histogram, and median and interquartile range were reported when the data were skewed. A correlation matrix was created to describe the relationships among continuous predictor variables using the Pearson correlation coefficient or the Spearman's rank correlation coefficient for skewed data.

In order to estimate the magnitude of the association and compare differences in the predictor variables for the primary outcome of safe return to sport, the following tests were performed. The chi-square test (or Fisher's exact test when expected cell sizes were too small) was used to compare the categorical variables of the 6-month clinical measures between those who made a safe return to sport vs those who did not. For continuous variables, 2-sided independent t-tests compared those that made a safe return to sport vs. those who did not, and the Wilcoxon rank-sum (Mann-Whitney U) test was used as the non-parametric equivalent. Correlations between predictor measures and the dichotomous outcome of safe return to sport was calculated using the point biserial correlation for continuous variables and the phi correlation for dichotomous variables.

The point-biserial correlation is described by the following equation:[219]

$$r_{pb} = \frac{(\mathrm{M}_{Y_1} - M_{Y_0})\sqrt{\mathrm{PQ}}}{\mathrm{sd}_Y}$$

Equation 1: Point Biseral Correlation

where M_{Y_1} and M_{Y_0} are the means of the continuous variable for each group of the dichotomous variable, P is the proportion in one group, Q is the proportion in the second group, and sd_y is the standard deviation of the sample value (divided by n instead of n-1).[219] As the correlation for two dichotomous variable, the phi coefficient can be calculated from the frequencies within the 2 x 2 table using the following equation:[219]

$$r_{\phi} = \frac{(\mathrm{BC} - \mathrm{AD})}{\sqrt{(\mathrm{A}+\mathrm{B})(\mathrm{C}+\mathrm{D})(\mathrm{A}+\mathrm{C})(\mathrm{B}+\mathrm{D})}}$$

Equation 2: Phi Correlation

The same analyses were performed for the secondary outcomes when assessing those that returned to preinjury level of sport vs. those who do not and those who experienced a reinjury vs. those who do not. A Kaplan–Meier curve was used to describe the cohort's timeline to return to preinjury level of sport. The level of significance for all analyses was $\alpha = 0.05$. As this is an exploratory aim, there were no adjustments made for multiple comparisons.

Sample size requirements were calculated using data from published literature[46,121,134,137,193] for the 6-month clinical measures with $\alpha = 0.05$ and $\beta = 0.80$. A recent study reported that the return to sport rate in athletes at 1 year after ACLR was 57%,[47] and estimating that a return to sport without reinjury will lower this proportion further, a 50% safe return to sport rate was estimated for the purposes of the sample size calculations. With 75 participants recruited and assuming a 15% drop out rate, 64 participants were calculated as sufficient to find significant differences between groups for the IKDC SKF, Marx Activity Scale, ACL-RSI, K-SES, and isokinetic hamstring strength. To find significant differences between groups within the additional 6-month measures, an effect size of 0.71 or greater was required with 64 participants in equal sized groups.

To assess the level of accuracy between the baseline and 6-month answers on the preinjury Sport Participation form, Cohen's Kappa was reported for the binary yes/no answer to the questions asking about participation in particular sports. Weighted Kappa was used for the ordinal questions assessing level of competition within each sport. The details of this analysis are described in Appendix C.1. All data were analyzed using Stata (StataCorp. 2021. Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC.).

5.3 Results

A total of 32 athletes consented to the study, and 30 participated in research activities (2 withdrew after informed consent but prior to research participation). Of these 30 athletes (17 males and 13 females), none were lost to follow-up. At the time of testing during the 6-month post-operative time point, the average age was 18.8 ± 2.9 years (Table 8). All participants were injured during sports; the sports with the highest frequency for injury were football (9 participants [30%]), soccer (8 participants, [27%]), and basketball (3 participants [10%]). The majority (n=16 or 53%) played 1 sport prior to injury, 9 (30%) played 2 sports, 1 (3%) played 3 sports, 3 (10%) played 4 sports, and 1 participant (3%) played 6 sports.

Table 8: Baseline Demographic Characteristics between the Safe Return to Sport Groups

Characteristic	Overall	Safe Return to Sport Group	No Safe Return to Sport Group
N	30	19	11
Age, mean (SD)	18.8 (2.9)	18.7 (3.0)	19.0 (2.7)
Sex, male, n (%)	17 (57)	10 (53)	7 (64)
BMI[a], kg/m^2, (median, IQR)	24.6 (22.6-27.3)	24.8 (21.8-26.6)	24.4 (23.7-30.9)
Racial/ethnic group n (%)			
American Indian/Alaska Native	1 (3)	1 (5)	0 (0)
Asian	2 (7)	2 (11)	0 (0)
Black or African American	7 (23)	6 (32)	1 (9)
Caucasian	21 (70)	13 (68)	8 (73)
Hispanic or Latino	1 (3)	0 (0)	1 (9)
Prior smoker, n (%)	1 (3)	1 (5)	0 (0)
Current smoker, n (%)	0 (0)		
Highest level of pre-injury sport played, n (%)			
Elite Sport	6 (20)	4 (21)	2 (18)
Varsity Sport	19 (63)	12 (63)	7 (64)
Competitive Sport	2 (7)	1 (5)	1 (9)
Recreational Sport	2 (7)	1 (5)	1 (9)
Non-organized Sport	1 (3)	1 (5)	0 (0)
Highest type of pre-injury sports played[d], n (%)			

Level I sport[b]	27 (90)	16 (84)	11 (100)
Level II sport[b]	3 (10)	3 (16)	0 (0)
Graft type, n (%)			
Patellar	12 (40)	9 (47)	3 (27)
Quadriceps	18 (60)	10 (53)	8 (73)
Concomitant Injury, n (%)			
Meniscal	16 (53)	11 (58)	5 (45)
Chondral	2 (7)	2 (11)	0 (0)

[a]BMI = Body Mass Index
[b]Level of sport played as described by Hefti *et al.* [26] Level I sports played by participants included soccer, American football, lacrosse, rugby, and volleyball. Level II sports played by participants included downhill skiing/snowboarding, softball/baseball, tennis/squash, wrestling, cheerleading, hockey, and kickball.

Nineteen out of 30 participants (63%) of the participants safely returned to preinjury level of sport by 12 months after surgery. Descriptively, there was a higher percentage of those in the safe return to sport group who had a patellar autograft and a lower percentage who had a quadriceps autograft as compared to the no safe return to sport group (Table 8).

As supporting evidence for the use of patient-reported preinjury sport participation data collected 6 months after surgery, the kappa values for recall of sport participation and level of competition within the STABILITY 2 sub cohort were 0.91 and 0.76 respectively (Appendix C.1).

Of the 11 participants who did not return to preinjury level of sport, 2 had a reinjury (7% of the total cohort). One participant suffered a contralateral ACL injury at 9.3 months after surgery, requiring a subsequent ACLR. The second participant had an ipsilateral medial meniscal tear at 11.6 months after surgery, also requiring surgery. Both participants had returned to sport participation but were not yet playing at preinjury levels, and they were participating in sports at the time they were reinjured.

The median time for return to preinjury level of sport estimated from the Kaplan Meier survival curve was 11.0 months (inter-quartile range: 10.3 months - .) (Figure 10). The missing 75th percentile is due to the high proportion of censoring in the data.

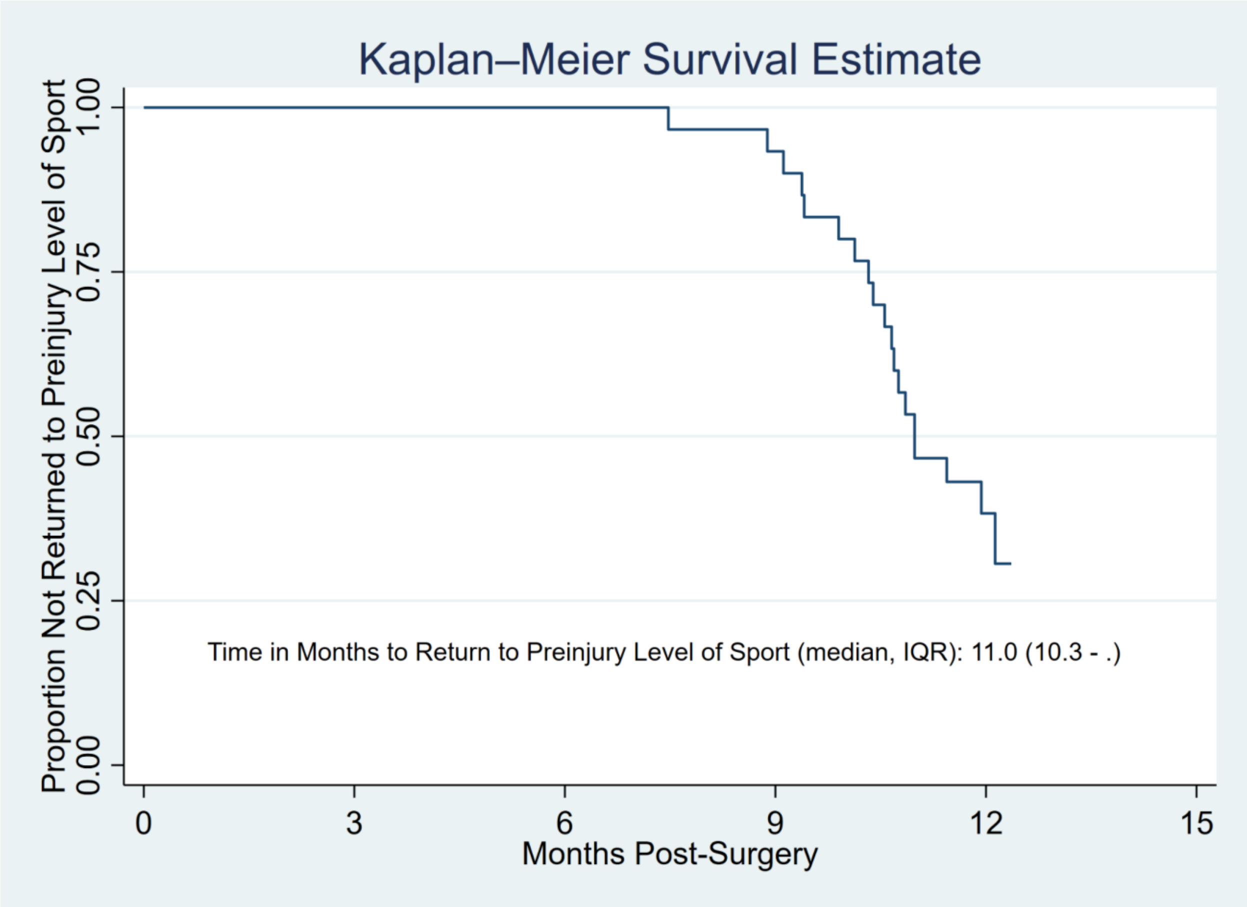


Figure 10: The Kaplan Meier Survival Curve for the Outcome of Return to Preinjury Level of Sport

Participants could select multiple reasons as needed for reasons why they did not return to sport when completing the return to sport form. Of the 11 participants who did not return to preinjury level of sport, 3 (27%) reported that they did not return to their primary sport due to not yet being cleared to play, 3 (27%) reported that they were too fearful of reinjury/have a lack of confidence in their knee, 2 (18%) reported that their interests had changed/did not have enough time, 2 (18%) reported that their sport was not available or the season had not yet started, 2 (18%) did not return due to reinjury, 1 (9%) had returned to partial participation (working out with the team and some participation in practice), and 1 (9%) had returned to his sport but at a lower level than before injury.

5.3.1 Correlation Among Continuous Predictor Measures

To understand the magnitude of the association between measures being considered as predictors, a correlation matrix was estimated for continuous measures. Spearman's Rank correlations were used due to the high proportion of skewed variables in the matrix (Table 9).

Table 9: Spearman's Rank Correlation for Continuous Study Variables

Correlation (p-value)	1	2	3	4	5	6	7	8	9	10	11	12	13
1. ACL-RSI[a]	_												
2. KSES Present[b]	**0.50 (.01)**	_											
3. KSES Future	**0.88 (<.001)**	**0.44 (.02)**	_										
4. BRS[c]	**0.47 (.01)**	-0.11 (.57)	**0.46 (.02)**	_									
5. Marx Activity Scale	0.14 (.48)	0.30 (.13)	0.37 (.06)	-0.15 (.46)	_								
6. SSQ Sources of Support[d]	0.09 (.66)	-0.01 (.94)	0.17 (.41)	0.05 (.80)	0.35 (.08)	_							
7. SSQ Satisfaction	**0.41 (.04)**	0.16 (.44)	**0.42 (.03)**	0.27 (.17)	-0.08 (.70)	0.30 (.13)	_						
8. IKDC SKF[e]	0.33 (0.10)	**0.58 (<.01)**	0.07 (.71)	-0.20 (.31)	0.08 (.70)	-0.39 (.05)	-0.03 (.89)	_					
9. Quadriceps Peak Torque LSI[f]	0.10 (.64)	**0.54 (<.01)**	0.12 (.55)	0.00 (.99)	**0.41 (.03)**	0.24 (.23)	-0.07 (.72)	0.19 (.34)	_				
10. Hamstring Peak Torque LSI	0.38 (.05)	**0.54 (<.01)**	0.22 (.27)	0.03 (.87)	0.05 (.79)	0.07 (.74)	0.04 (.84)	0.20 (.33)	0.38 (.05)	_			
11. Quadriceps Average Power LSI	0.16 (.43)	**0.47 (.01)**	0.22 (.26)	-0.05 (.82)	**0.59 (<.01)**	**0.43 (.02)**	-0.04 (.85)	0.08 (.70)	**0.84 (<.001)**	**0.44 (.02)**	_		
12. Hamstring Average Power LSI	**0.53 (<.01)**	**0.52 (<.01)**	**0.45 (.02)**	0.15 (.47)	0.06 (.77)	-0.29 (.14)	0.11 (.60)	**0.44 (0.02)**	0.08 (.70)	**0.57 (>.01)**	0.15 (.45)	_	
13. Double Leg RSI[g]	0.09 (.64)	0.24 (.22)	0.15 (.46)	0.08 (.69)	0.29 (.14)	0.15 (.46)	-0.15 (.45)	0.11 (.58)	0.22 (.28)	0.09 (.64)	0.18 (.37)	-0.26 (.20)	_

a=ACL Return to Sport after Injury scale, b=Knee Self-Efficacy Scale, c= Brief Resilience Scale, d=Social Support Questionnaire, e=International Knee Documentation Committee Subjective Knee Form, f=Limb Symmetry Index, g=Reactive Strength Index

The Knee Self-Efficacy Scale (K-SES) present and future subscales had positive, moderate (0.50) and strong (0.88) correlations with the ACL-Return to Sport after Injury Scale (ACL-RSI), respectively. The two subscales had a moderate correlation with each other (0.44). The K-SES future subscale had a positive, moderate correlation with the Brief Resiliency Scale (BRS) (0.46) and with the satisfaction with social support in the social support questionnaire (SSQ) (0.42). The ACL-RSI had a positive, moderate correlation with BRS (0.47) and with the satisfaction score of the SSQ (0.41). The K-SES present subscale had a positive, moderate correlation with the International Knee Documentation Committee Subjective Knee Form (IKDC SKF) (0.58).

Several isokinetic strength testing variables had correlations with patient-reported measures. K-SES present had a positive, moderate correlation with both isokinetic quadriceps and hamstring peak torque LSI (0.54 for both) and quadriceps and hamstring average power LSI (0.47 and 0.52, respectively). The K-SES future subscale, the ACL-RSI, and the IKDC SKF were positively associated with hamstring average power LSI (0.45, 0.53, and 0.44 respectively). Quadriceps average power LSI was positively associated with the number of sources of social support from the SSQ and with the Marx Activity Scale (0.43 and 0.59, respectively).

Finally, there were several isokinetic strength testing variables that were correlated with each other. Hamstring average power LSI had a positive, moderate correlation with hamstring peak torque LSI (0.57). Quadriceps average power LSI had a strong positive correlation with quadriceps peak torque LSI (0.84) and a moderate positive correlation with hamstring peak torque LSI (0.44).

5.3.2 Between-group Differences for Safe Return to Sport

Tables 10 and 11 report the averages or medians for the entire cohort, for the safe return to sport and the no safe return to sport groups, the difference between groups, and the correlation with safe return to sport for the patient-reported measures and performance-based measures of physical function, respectively. For the primary outcome of safe return to sport, comparison between groups demonstrated higher scores on the Knee Self-Efficacy Scale (K-SES), future subscale, in those who safely returned to sport (n=19, median score = 7.5) vs those who did not (n=11, median score = 6.5) (Wilcoxon rank sum p = .04). Furthermore, there was a moderate positive point biserial correlation between scores on the K-SES future subscale and safe return to sport (correlation = 0.45, p = .01).

Athletic exposures (AEs) per month were different between groups when calculating exposures during the last 3 months when athletes were most active in sports (p<.001). Athletes that safely returned to sports were participating in sport activity at a much higher median level vs those who did not (24.0 AEs per month compared to 3.5 AEs per month for months 10-12). Appendix C.2 shows the scatter plots of monthly AEs over the course of the study for the safe return to sport group compared to the group that did not safely return to sports. A total of 7% (13/195 forms completed) of the forms were considered to be an estimation when a participant filled out the form past the deadline for reporting their sport participation for the month.

Since there were not any group membership differences in those who safely returned to sport and in those who returned to preinjury level of sport, the outcome of return to preinjury level of sport was not recalculated. All estimates of magnitude of the association for safe return to sport can also apply to return to preinjury level of sport.

Table 10: Comparison between Safe Return to Sport Groups for Patient-reported Outcomes

Patient-reported Outcome Measures	Overall Mean (SD)[a]	Safe Return to Sport Group	No Safe Return to Sport Group	Mean Difference (95% CI)	Correlation with safe return to sport, *p* value
ACL-Return to Sport after Injury Scale	64.2 (19.3)	68.2 (14.1)	57.4 (25.3)	10.8 (-7.0-28.6)	0.27[b], .15
Knee Self-Efficacy Scale					
$K\text{-}SES_{present}$ (median, IQR)	8.5 (6.6-8.9)	8.6 (7.7-9.4)	6.7 (5.5-8.8)	*p* =.13[c] 1.2 (-0.1-2.5)	0.32[b], .08
$K\text{-}SES_{future}$ (median, IQR)	**7.3 (6.0-9.0)**	**7.5 (6.5-9.0)**	**6.5 (3.0-7.5)**	***p* =.04[c] 2.1 (0.2-4.0)**	**0.45[b], .01**
Brief Resiliency Scale	3.8 (0.7)	3.8 (0.8)	3.6 (0.6)	0.2 (-0.3-0.8)	0.15[b], .44
High knee-related confidence,[d] n (%)	5 (16.7)	2 (11%)	3 (27%)[e]	16%, *p*= .33[f]	0.22[g], .24
Marx Activity Scale	8.2 (5.5)	8.9 (5.3)	6.8 (5.8)	2.1 (-2.1-6.4)	0.19[b], .32
Social Support Questionnaire					
Sources of Social Support	2.6 (1.0)	2.5 (1.1)	2.8 (1.0)	-0.3 (-1.1-0.5)	-0.14[b], .45
Degree of Satisfaction with Support (median, IQR)	5.8 (5.3-6.0)	5.8 (5.3-6.0)	6.0 (5.5-6.0)	*p* = .57[c] -0.2 (-0.8-0.3)	-0.14[b], .47
IKDC SKF[h]	76.9 (12.9)	77.9 (10.5)	75.1 (16.7)	2.7 (-7.4-12.8)	0.10[b], .59

[a]Continuous variables are reported as mean (standard deviation) unless otherwise noted as median and inter-quartile range (IQR)
[b]Point bi-serial correlation
[c]Wilcoxon rank-sum (Mann-Whitney U) test performed; mean difference (95% CI (confidence interval)) is listed below the p value for the Wilcoxon rank-sum results.
[d]High knee-related confidence was determined by the 3rd question on the Knee Injury and Osteoarthritis Outcome Score (KOOS) quality of life subscale, “How much are you troubled with lack of confidence in your knee?” Those who reported “never” were classified as having high knee-related confidence.
[e]1 of the 3 participants with high-knee related confidence in the No Safe Return to Sport group suffered a reinjury.
[f]Fisher’s exact test performed; Absolute difference in the percentages in each group is listed as the difference
[g]Phi correlation coefficient
[h]IKDC SKF = International Knee Documentation Committee Subjective Knee Form

There were no differences detected between groups in the performance-based measures of physical function. When a participant had a >20% deficit in peak torque quadriceps strength and/or apprehension in performing the test, they did not perform hop testing for the operative limb, or the carioca or plyometric jump test on the operative limb. Due to the non-ignorable missingness, proportions were reported for those who completed those tests in each group (Table 11).

Individual limb performance on the non-operative limb was still collected for the hop test. These results with the individual limb performance for isokinetic quadriceps and hamstring strength testing are listed in Appendix C.3, Supplemental Table 12. There were no differences detected.

Table 11: Comparison Between Safe Return to Sport Groups on Performance-based Measures of Physical Function

Performance-Based Measure of Physical Function	Overall Mean (SD)[a]	Safe Return to Sport Group	No Safe Return to Sport Group	Mean Difference (95% CI)	Correlation with safe return to sport, *p* value
Hop and Carioca Tests					
Completed hop tests? Yes, n (%)	10 (33)	6 (32)	4 (36)	4%, $p = 1.00$[b]	0.05[c], .79
Completed carioca test? Yes, n (%)	16 (53)	12 (63)	4 (36)	27%, $p = .16$[d]	0.26[c], .16
Drop Vertical Jump					
Knee-ankle separation ratio at initial contact (median, IQR)	1.00 (0.87-1.08)	1.01 (0.89-1.08)	0.93 (0.85-1.12)	$p = .62$[e] 0.02 (-0.10-0.14)	0.07[f], .73
Knee-ankle separation ratio at peak flexion (median, IQR)	1.12 (0.93-1.22)	1.13 (0.96-1.22)	1.03 (0.88-1.23)	$p = .75$[e] 0.01 (-0.13-0.16)	0.03[f], .87
Plyometric Jump RSI[g] (cm/ms) (median, IQR)					
Double leg	0.05 (0.04-0.09)	0.05 (0.04-0.09)	0.06 (0.04-0.06)	$p = .92$[e] 0.002 (-0.03-0.03)	0.03[f], .86
Non-operative limb	0.03 (0.02-0.05)	0.03 (0.02-0.05)	0.03 (0.02-0.04)	$p = .84$[e] 0.01 (-0.01-0.03)	0.19[f], .34
Complete operative limb testing? Yes, n (%)	22 (73)	13 (68)	9 (82)	14%, $p = .67$[b]	0.15[c], .42
Quadriceps Isokinetic Strength at 90°/sec					
Peak Torque LSI[h]	67.7 (17.1)	67.9 (16.1)	67.5 (19.6)	0.4 (-13.1-14.0)	0.01[f], .95
Average Power LSI (median, IQR)	72.5 (64.7-88.3)	72.1 (67.5-88.3)	72.9 (53.2-97.8)	$p = .78$[e]	-0.17[f], .36

				-18.2 (-70.0-33.6)	
Hamstring Isokinetic Strength at 90°/sec					
Peak Torque LSI	91.9 (18.4)	95.0 (15.7)	86.6 (22.1)	8.4 (-5.8-22.6)	0.22[f], .24
Average Power LSI (median, IQR)	103.6 (90.9-115.6)	105.5 (96.8-123.9)	97.0 (79.3-114.1)	*p* =.35[e] 14.5 (-28.3-57.3)	0.13[f], .50
Hamstring/Quadriceps Peak Torque Ratio					
Non-operative Limb (median, IQR)	0.54 (0.50-0.62)	0.57 (0.50-0.62)	0.52 (0.50-0.62)	*p* =.56[e] 0.005 (-0.11-0.12)	0.02[f], .93
Operative Limb (median, IQR)	0.79 (0.63-0.99)	0.83 (0.64-0.99)	0.74 (0.56-1.00)	*p* =.50[e] 0.03 (-0.15-0.21)	0.06[f], .73

[a]Continuous variables are reported as mean (standard deviation) unless otherwise noted as median and inter-quartile range (IQR)
[b]Fisher's exact test performed; Absolute difference in the percentages in each group is listed as the difference.
[c]Phi coefficient correlation
[d]Chi-squared test performed
[e]Wilcoxon rank-sum (Mann-Whitney U) test performed
[f]Point bi-serial correlation
[g]RSI = Reactive strength index; System error prevented 2 participants from completing the plyometric jump at all (n=28 for double leg version) and 1 from completing the single-leg plyometric jumps (n = 27 for the nonoperative side). An additional 5 participants had apprehension in completing the operative side plyometric jump, and therefore, the operative side plyometric jump data is presented only as those who completed the test (n = 22). Of the 6 participants who did not complete the operative side plyometric jump in the Safe Return to Sport Group, 4 (66%) had apprehension performing the test. Of the 2 participants who did not complete the operative side plyometric jump in the No Safe Return to Sport Group, 1 (50%) had apprehension performing the test.
[h]Limb Symmetry Index

5.3.3 Between-group Differences for Reinjury

Overall, the reinjured group (n=2) tended to perform better on the patient-reported outcomes and performance-based measures of physical function as compared to those who did not have a reinjury (n=28). With only 2 participants who experienced a reinjury, inferential statistics were not reported. The data for comparison of those that had a reinjury compared to those that did not are presented in Appendix C.3, Supplemental Table 13 (patient-reported measures), Supplemental Table 14 (performance-based measures of physical function), and Supplemental Table 15 (individual limb hop and strength testing).

5.4 Discussion

The findings of this study are hypothesis-generating and provide preliminary data for larger cohort studies to incorporate variables across the range of biological, psychological, and social factors. Results between those that did versus did not safely return to sport 12 months after ACLR provide data needed to calculate appropriate sample sizes to ensure that meaningful associations and differences will be detected.

Sixty-three percent of this cohort of young athletes returned to preinjury level of sport within 1 year after ACLR. This is a similar rate to what has been found for return to preinjury level of sport in the literature.[5] The median time to return to preinjury level of sport was approximately 11 months, and this is similar to previous findings in a similar patient population.[114] The overall reinjury rate in this cohort with 2 knee reinjuries (1 contralateral and 1 ipsilateral) was

7%. Previous research has reported up to 20% reinjury rate in young athletes.[70] It is likely that not all reinjuries have occurred by 1 year after surgery as previous findings have demonstrated that athletes are at a greater risk for reinjury within the first 24 months after return to sport.[205] With only 2 reinjuries occurring by 12 month after surgery, conclusions about the differences between those who had a reinjury vs those who did not should not be inferred to the population.

Reasons for not returning to sport are varied and multifactorial. A few of the reasons given by this cohort were non-modifiable, such as the sport not being available or season not starting. Two others said their interests had changed or they did not have time. However, both fear of reinjury/lack of confidence in their knee and not yet being cleared to play were given as a reason for not returning to sport for 27% of the participants. Fear of reinjury is a common and major barrier to returning to sport after ACLR.[110] In cases like these, it may be possible for the rehabilitation team to continue to work with the athlete to address individual concerns and deficits, both psychologically and physically, to give them the best chance of returning to sport and being prepared to do so. These participants may go on to eventually return to sport past the 12-month post-operative time point. The authors plan to continue following participants to 24 months after surgery in order to more fully capture return to sport and reinjuries within this cohort.

5.4.1 Correlations among Predictor Variables

The several correlations among predictor measures quantified the strength of the relationship, and this can be used in future studies to choose appropriate measures for a regression analysis to avoid the problem of multicollinearity. The largest correlation was between the ACL-RSI and the future subscale of the K-SES (Spearman's rank correlation = 0.88). This was an interesting finding as prior research has reported a relatively weak correlation between these two measures (r = 0.37, *p* <0.0001).[209] The moderate correlations between the future subscale of the K-SES with the BRS and SSQ along with moderate correlation between the ACL-RSI and the BRS are to our knowledge the first to be reported for these specific scales. Given that the constructs of self-efficacy, psychological readiness to return to sport, resilience, and social support are conceptually related and have demonstrated relationships with one another in research, it is not surprising that these correlations were found.[135,144,210,220,221]

The K-SES present subscale's moderate correlation with the IKDC SKF conceptually aligns with the fact that the present subscale intends to measure the current, perceived self-efficacy of knee function[132] and the IKDC SKF represents the current symptoms and limitations in function and sports due to knee impairment.[119] One previous study found that 12-week changes in self-efficacy after ACLR predicted changes in the IKDC SKF.[222]

The moderate-strength relationships between the K-SES future subscale and hamstring average power LSI and between the K-SES present subscale and both hamstring and quadriceps average power and peak torque LSI are in line with recent findings. One study has reported that those who perform better on the LSI for hop tests and for isokinetic strength tested at 90 degrees per second have significantly higher K-SES present scores.[223] The correlation between the ACL-RSI and flexion average power LSI is moderate (0.53) in comparison to a recent study that found weak to no correlations of the ACL-RSI to strength and power measurements after ACLR.[224] The moderate correlation (0.44) between the IKDC SKF and hamstring average power was similar in magnitude (0.46) at a comparable time point for patients who underwent an ACLR.[225] Finally, the moderate correlations between the Marx Activity Scale and the social support questionnaire and quadriceps average power are believed to be the first reported.

5.4.2 Differences in Those that made a Safe Return to Sport Compared to those that Did Not

The athletes in the safe return to sport group scored higher on the future subscale of the Knee Self-Efficacy scale (Wilcoxon rank sum $p = .04$), with a median score of 7.5 in the safe return to sport group and a 6.5 in the no safe return to sport group. The point-biserial correlation of 0.45 indicates a moderately strong relationship between the K-SES score on the future subscale and the outcome of safe return to sport. This finding is consistent with a recent meta-analysis.[135] In the systematic review by Everhart, Best, and Flanigan, self-efficacy and belief in a successful recovery was related to actual outcomes after ACLR.[226] Specific to future subscale of the K-SES, Thomeé and colleagues found that future knee self-efficacy was a predictor of self-rated knee function in sports/recreational activity. As the future subscale is short and easy to fill out in a busy clinical setting, this could be a reasonable psychosocial patient-reported measure to have athletes fill out around 6 months after surgery if validated as a predictor of safe return to sport after ACLR.

The higher scores on the K-SES present subscale (1.2-point mean difference (95% CI (confidence interval): -0.1 – 2.5); 1.9-point median difference) and the Marx Activity Scale (2.1-point mean difference (95% CI: -2.1 – 6.4) in the safe return to sport group compared to the no safe return to sport group may be clinically important differences. Previous studies have suggested that more than a one point difference on the knee self-efficacy scale[223,227] and a two point difference on the Marx Activity Scale[228] are clinically meaningful differences. The estimates of differences reported in this study are limited by the small sample size and should be investigated further.

The monthly exposures data reflected the progressive increase in sports activity in the safe return to sport group. These data were calculated as the average number of games and practices per month per participant. The average monthly AEs in each group demonstrated that there were still some athletes participating in sports activity in the no safe return to sport group but at a much lower median level as compared to the safe return to sport group (24.0 AEs per month compared to 3.5 AEs per month for months 10-12).

There were no differences detected in any of the performance-based measures. Due to the missing data in hop, carioca, and single-leg plyometric jump tests, this study was not able to compare these measures beyond the proportions who completed the tests in each group.

5.4.3 Future Directions

This study lays the foundation for understanding the magnitude of the associations for clinically-feasible predictor measures that represent the interrelated biological, psychological, and social domains that impact safe return to sport after ACLR. Larger, prospective cohort studies will be able to utilize these estimates to ensure that the study is adequately powered while incorporating the most important impairment-based and contextual factors that affect return to sport and reinjury after ACLR.

Future research should also explore what interventions are effective for enhancing the recovery of athletes to address the main modifiable reasons for not returning to sport, such as fear of reinjury. Powerful predictor measures and effective interventions will optimize rehabilitation programs to enhance the athlete's ability to safely return to their pre-injury level of sports.

5.4.4 Limitations

This study has several limitations. A 1-year follow up time after surgery is unlikely to capture everyone who will return to preinjury level of sport and all reinjuries within those who return to sport. Follow-up times of at least 24 months will ensure that these main outcomes are captured.

The small sample size did not allow for a more powerful and comprehensive analysis of the data. Ideally, a multi-variable regression analysis would have allowed important factors to be adjusted for and a more accurate estimate of the differences between groups. Due to the small sample size, it is possible that differences between groups that exist in the population were not able to be detected.

This study was limited to young athletes at high risk for reinjury who planned to return to sport. They were only recruited from one site in Pittsburgh, PA, and therefore, the generalizability of these results is limited.

5.5 Conclusion

This prospective, cohort study found that 63% of athletes at high risk for reinjury safely returned to sport by 1 year after ACL reconstruction. Those who returned to sport had higher scores on the Knee Self-Efficacy Scale, future subscale, compared to those who did not. Seven percent of the cohort suffered a reinjury during the same time frame. This evidence represents preliminary findings that should provide estimates of the magnitude of the association for future prospective studies.

6.0 Conclusion

The objective of this body of work was to expand existing knowledge of the incidence of ACL injury and to lay the groundwork for predicting safe return to activity in those at highest risk for suboptimal outcomes. The aims of this study were approached through the lens of a novel theoretical framework that incorporated the multifactorial nature of return to activity after ACL injury and reconstruction. This framework included relevant biological, psychological, and social factors along the timeline of return to activity after ACLR. The first aim sought to update our understanding of the incidence and risk factors of ACL injury in the military justified by the changes over time in policy and operational tempo and the impact that ACL injury has on command readiness. The second and third aims laid the groundwork for filling the gaps in our understanding of predictors of return to activity and reinjury in individuals who were highly active prior to injury.

In our first aim, we evaluated the trends over time and the effects of military occupation, sex, rank, and service branch on the risk of ACL injury for all US military members. There was a 4.1% decrease in the incidence of ACL injuries between the years 2006 and 2018. We hypothesized that this decrease represents a real trend with decrease in operation tempo as a contributing factor. The interaction effect of sex and time revealed that the rate of decrease over time was higher in males compared to females when considering rank and branch of service. We hypothesized that this trend could be influenced by the recent integration of females into all occupations in the military. The relationship of ACL injury incidence and sex was modified by rank, with female officers demonstrating an increased risk compared to males regardless of occupation. This was contrasted by enlisted females who demonstrated a lower risk compared with males, which challenges the assumption that young, physically active females are at the highest risk for ACL injury. The incidence of ACL injury varied by occupation among enlisted personnel and officers, and those occupations where vehicles were primarily employed or were more sedentary in nature had the lower risk of ACL injury. This study highlighted the overall decline of ACL injury and the salient risk factors of ACL injury in the military population to identify subgroups who are at higher risk of injury.

The second aim was a systematic review and meta-analysis of the literature investigating which performance-based and patient-reported measures of physical function predict return to activity and reinjury after ACLR. Only 7 studies were eligible, and all participants in the included studies were athletes. This revealed the lack of prognostic studies in military members and in athletes playing level 1 and 2 sports with at least 100 hours of sport activity per year, with large variability in the type of athletes included in the studies, return to sport tests utilized, and outcomes assessed. Within individual studies, lower extremity strength was a commonly reported significant predictor of reinjury.   Strength, hop tests, movement quality assessment, and scores on activity scales predicted return to activity along the return to sport continuum.   The only significant pooled effect size was significantly better individual limb performance of the side hop in those who returned to preinjury level of sport compared to those who did not (Hedge's g, ipsilateral side 0.42 (95% CI (0.06-0.78), contralateral side 0.46 (0.13-0.78)). The results of this review informed some of the measures of physical function included in the third aim.

The third aim was a prospective observational cohort study investigating the magnitude of associations of clinically applicable measures at 6 months after ACLR with safe return to preinjury sports one year after surgery in skeletally mature athletes who are at high risk for reinjury. These measures included performance-based and patient-reported measures of physical function and patient-reported psychosocial measures. In agreement with recent literature, we found that 63% of our cohort of young athletes returned to preinjury level of sport within 1 year after ACLR, with a median return to sport of approximately 11 months. Those who returned to sport had higher scores on the Knee Self-Efficacy Scale, future subscale, compared to those who did not. This adds to the evidence that emphasizes the importance of psychosocial measures and supports self-efficacy as an important factor for successful outcomes after ACLR. Seven percent of our cohort suffered a reinjury during the same time frame. This was comprised of only two athletes who had a second knee injury. The preliminary findings of this aim provide estimates of the magnitude of the association for future prospective studies.

6.1 Clinical Implications

The findings of these three studies have specific implications for practice for military and athletic populations. The epidemiological data from the first aim quantified ACL risk in the military population and within subpopulations. Policy makers cannot take informed action to limit risk of injury without first knowing who is at highest risk. The first paper laid the groundwork to guide appropriate prophylactic measures when risk can be mitigated and should be used as a starting point to justify continued surveillance of ACL injury along with exploration of hazards and exposures within these subgroups. For example, high-risk subgroups may benefit from interventions like movement training courses tailored to military members, such as the Military Movement course, which has been shown to improve biomechanical parameters during jump landings in cadets at the US Military Academy.[229] In our systematic review and meta-analysis, we found that while there was a lack of standardization of the measures used for return to sport testing, that the categories of tests clinicians should use to guide testing for athletes after ACLR included lower extremity strength, hop tests, quality assessment of jump landings, and validated patient-reported measures that include activity scales. We found that individual limb performances on performance-based measures of physical function, such as the side hop, more frequently differentiated between those who returned to sport and had a reinjury vs. those who did not. We were not able to make specific recommendations of cut-off scores for individual tests or the ideal test battery criteria for clinicians. Our final aim reinforced the importance of psychosocial measures as those who returned to sport by 1 year after ACLR had significantly higher future knee self-efficacy. These findings would need to be validated in a larger, prospective cohort study with investigation into appropriate thresholds for predictors of safe return to sport prior to clinical implementation.

6.2 Future Directions

This dissertation added important context with which to build future research in ACL injury surveillance and in improvement of outcomes after ACL reconstruction for the military and athletic populations most affected by this devastating knee injury. In the military, surveillance of ACL injury should continue as the proportion of females in previously restricted combat roles grows. The next steps in injury prevention in the military are to critically evaluate the groups at highest risk and identify what are the granular modifiable exposures and risk factors that can be mitigated. Optimizing rehabilitation and outcomes after ACL reconstruction will require considering the individual as a whole, to include impairment-based measures and contextual factors. High quality, observational studies are needed in both highly active athletes and military members to move towards a specific, standardized and highly prognostic test battery to predict safe return to activity. Future research should explore what are the most effective interventions for enhancing recovery of athletes and military members after ACL reconstruction once an individual is found to be at risk for not safely returning to activity.

Appendix A : Supplemental Tables 1-4 for "Sex, Military Occupation and Rank are Associated with Risk of Anterior Cruciate Ligament Injury in Tactical-Athletes"

Supplemental Table 1: ACL injury counts, population at risk, and injury rates (per 1,000 person-years) by year for Male Officers

Counts	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Army	372	360	375	352	384	412	356	360	348	281	278	248	202	4,328
Navy	226	192	189	194	179	144	135	166	146	128	101	117	100	2,017
Air Force	307	300	257	209	193	224	206	188	189	155	148	145	152	2,673
Marines	82	84	84	74	101	85	80	79	62	58	66	62	48	965
Total	987	936	905	829	857	865	777	793	745	622	593	572	502	9,983
Population														
Army	69,311	71,314	73,556	76,044	78,737	81,506	82,562	82,654	81,903	79,386	76,947	74,910	75,110	1,003,939
Navy	44,641	44,059	43,828	43,986	44,341	44,732	44,667	44,699	45,016	44,766	44,622	44,270	44,342	577,969
Air Force	58,175	55,391	53,124	53,237	53,485	52,821	52,042	51,692	50,635	48,324	47,944	46,467	46,317	669,654
Marines	17,900	18,280	18,869	19,626	20,223	20,886	20,727	20,296	19,777	19,436	19,307	19,406	19,713	254,446
Total	190,027	189,044	189,378	192,893	196,786	199,944	199,998	199,341	197,330	191,912	188,820	185,053	185,481	2,506,008
Rate														
Army	5.4	5.0	5.1	4.6	4.9	5.1	4.3	4.4	4.2	3.5	3.6	3.3	2.7	4.3
Navy	5.1	4.4	4.3	4.4	4.0	3.2	3.0	3.7	3.2	2.9	2.3	2.6	2.3	3.5
Air Force	5.3	5.4	4.8	3.9	3.6	4.2	4.0	3.6	3.7	3.2	3.1	3.1	3.3	4.0
Marines	4.6	4.6	4.5	3.8	5.0	4.1	3.9	3.9	3.1	3.0	3.4	3.2	2.4	3.8
Total	5.2	5.0	4.8	4.3	4.4	4.3	3.9	4.0	3.8	3.2	3.1	3.1	2.7	4.0

Supplemental Table 2: ACL injury counts, population at risk, and injury rates (per 1,000 person-years) by year for Female Officers

Counts	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Army	78	60	72	65	74	87	75	70	76	76	65	52	63	913
Navy	29	37	37	46	28	44	34	32	35	24	27	36	35	444
Air Force	61	52	75	66	62	62	59	57	61	49	53	37	48	742
Marines	9	6	9	3	16	3	5	6	8	6	13	10	5	99
Total	177	155	193	180	180	196	173	165	180	155	158	135	151	2,198
Population														
Army	12,563	12,858	13,418	14,189	14,876	15,498	15,883	16,059	16,158	15,921	15,666	15,492	15,859	194,440
Navy	7,671	7,612	7,704	7,901	8,141	8,427	8,625	8,869	9,137	9,328	9,639	9,919	10,262	113,235
Air Force	13,032	12,263	11,784	11,967	12,203	12,182	12,233	12,518	12,531	12,165	12,334	12,374	12,623	160,209
Marines	1,127	1,124	1,161	1,201	1,264	1,312	1,354	1,379	1,426	1,454	1,507	1,566	1,639	17,514
Total	34,393	33,857	34,068	35,258	36,483	37,419	38,096	38,825	39,253	38,867	39,145	39,351	40,383	485,398
Rate														
Army	6.2	4.7	5.4	4.6	5.0	5.6	4.7	4.4	4.7	4.8	4.1	3.4	4.0	4.7
Navy	3.8	4.9	4.8	5.8	3.4	5.2	3.9	3.6	3.8	2.6	2.8	3.6	3.4	3.9
Air Force	4.7	4.2	6.4	5.5	5.1	5.1	4.8	4.6	4.9	4.0	4.3	3.0	3.8	4.6
Marines	8.0	5.3	7.7	2.5	12.7	2.3	3.7	4.3	5.6	4.1	8.6	6.4	3.1	5.7
Total	5.1	4.6	5.7	5.1	4.9	5.2	4.5	4.2	4.6	4.0	4.0	3.4	3.7	4.5

Supplemental Table 3: ACL injury counts, population at risk, and injury rates (per 1,000 person-years) by year for Enlisted Males

Counts	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Army	2,141	2,243	2,377	2,385	2,553	2,505	2,399	2,293	1,970	1,640	1,495	1,301	1,064	26,366
Navy	1,399	1,239	1,249	1,236	1,167	1,134	1,029	1,057	969	856	793	668	621	13,417
Air Force	1,229	1,254	1,200	1,099	1,070	1,132	1,105	1,041	950	807	907	705	699	13,198
Marines	979	1,032	952	1,032	995	1,011	991	854	749	631	626	585	540	10,977
Total	5,748	5,768	5,778	5,752	5,785	5,782	5,524	5,245	4,638	3,934	3,821	3,259	2,924	63,958
Population														
Army	356,602	368,968	385,276	397,813	406,484	407,158	392,488	375,912	357,011	339,619	325,696	321,308	322,174	4,756,511
Navy	252,588	241,732	235,115	232,772	228,757	224,608	218,499	217,744	218,836	219,525	218,162	213,620	216,444	2,938,404
Air Force	219,775	212,992	207,765	211,088	213,972	214,062	214,789	215,002	209,281	200,777	202,960	207,575	209,625	2,739,662
Marines	149,900	152,982	162,916	170,257	169,126	166,945	163,060	160,424	155,635	150,625	149,883	149,024	149,423	2,050,201
Total	978,865	976,674	991,073	1,011,930	1,018,340	1,012,773	988,837	969,083	940,763	910,546	896,701	891,528	897,665	12,484,777
Rate														
Army	6.0	6.1	6.2	6.0	6.3	6.2	6.1	6.1	5.5	4.8	4.6	4.0	3.3	5.5
Navy	5.5	5.1	5.3	5.3	5.1	5.0	4.7	4.9	4.4	3.9	3.6	3.1	2.9	4.6
Air Force	5.6	5.9	5.8	5.2	5.0	5.3	5.1	4.8	4.5	4.0	4.5	3.4	3.3	4.8
Marines	6.5	6.7	5.8	6.1	5.9	6.1	6.1	5.3	4.8	4.2	4.2	3.9	3.6	5.4
Total	5.9	5.9	5.8	5.7	5.7	5.7	5.6	5.4	4.9	4.3	4.3	3.7	3.3	5.1

Supplemental Table 4: ACL injury counts, population at risk, and injury rates (per 1,000 person-years) by year for Enlisted Females

Counts	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Army	317	284	300	311	291	335	291	277	235	221	210	172	162	3,406
Navy	157	155	171	174	120	147	160	151	148	152	149	140	129	1,953
Air Force	218	227	184	209	190	157	164	174	159	148	127	150	145	2,252
Marines	55	57	55	59	74	78	54	52	63	44	45	54	49	739
Total	747	723	710	753	675	717	669	654	605	565	531	516	485	8,350
Population														
Army	57,078	57,448	58,491	59,505	60,574	60,858	58,291	56,108	54,367	53,170	52,769	53,278	53,860	735,798
Navy	42,281	40,962	40,877	41,868	42,966	43,936	44,216	46,119	47,615	49,165	50,548	50,825	52,944	594,325
Air Force	55,031	53,268	51,798	52,144	51,625	50,689	50,062	49,662	48,046	46,445	47,724	49,930	51,819	658,244
Marines	9,955	10,320	10,954	11,622	12,120	12,419	12,484	12,710	12,816	12,703	13,165	13,716	14,136	159,121
Total	164,345	161,998	162,120	165,140	167,286	167,902	165,054	164,600	162,844	161,484	164,207	167,749	172,759	2,147,488
Rate														
Army	5.6	4.9	5.1	5.2	4.8	5.5	5.0	4.9	4.3	4.2	4.0	3.2	3.0	4.6
Navy	3.7	3.8	4.2	4.2	2.8	3.3	3.6	3.3	3.1	3.1	2.9	2.8	2.4	3.3
Air Force	4.0	4.3	3.6	4.0	3.7	3.1	3.3	3.5	3.3	3.2	2.7	3.0	2.8	3.4
Marines	5.5	5.5	5.0	5.1	6.1	6.3	4.3	4.1	4.9	3.5	3.4	3.9	3.5	4.6
Total	4.5	4.5	4.4	4.6	4.0	4.3	4.1	4.0	3.7	3.5	3.2	3.1	2.8	3.9

Appendix B : Supplemental Data for "Prognosis for Return to Sport and Reinjury in Athletes and Military after Anterior Cruciate Ligament Reconstruction: A Systematic Review"

Appendix B.1 Search Strategies and Non-database Searches Yielding New Studies

Supplemental Table 5: Summary of Databases Searched

Table	Vendor/ Interface	Database	Date searched	Database update	Searcher(s)
1a	Ovid	Medline®	June 8, 2020; Update 1: January 6, 2021; Update 2:January 27, 2022	1946 to June 05, 2020; Update 1: 1946 to January 04, 2021; Update 2: 1946 to January 26, 2022	Helena M. VonVille; Aubrey Aguero
1b	Elsevier	Embase®	June 8, 2020; Update 1: January 6, 2021; Update 2: January 27, 2022	June 8, 2020; Update 1: January 6, 2021; Update 2: January 27, 2022	Helena M. VonVille
1c	Ebsco	CINAHL	June 16, 2020; Update January 6, 2021	June 16, 2020; Update January 6, 2021	Helena M. VonVille

Note: This template is based on:
Niederstadt C, Droste S. Reporting and presenting information retrieval processes: the need for optimizing common practice in health technology assessment. Int J Technol Assess Health Care. 2010;26(4):450-7.

Appendix B.1.1 Medline Search Strategy

Supplemental Table 6: Medline Search Strategy

Provider/Interface	Ovid
Database	Medline®
Date searched	June 8, 2020; Update January 6, 2021; Update January 27, 2022
Database update	1946 to June 05, 2020; Update 1946 to January 04, 2021; Update 1946 to January 26, 2022
Search developer(s)	Helena M. VonVille; Aubrey Aguero
Limit to English	Yes
Date Range	No date limitations set
Publication Types	No publication type limitations set
Search filter source	http://bit.ly/Ovid-Medline-Search-Filters

1	anterior cruciate ligament reconstruction/
2	Anterior Cruciate Ligament/ or Anterior Cruciate Ligament Injuries/
3	(acl or anterior cruciate ligament).ti,ab,kw.
4	2 or 3
5	(su or tr).fs.
6	orthopedic procedures/ or arthroplasty/
7	(arthroplast* or graft* or orthopedic* or reconstruction or repair* or surgery or surgical or transplant*).ti,ab,kw.
8	5 or 6 or 7
9	(4 and 8) or 1
10	athletic performance/ or baseball/ or basketball/ or bicycling/ or boxing/ or diving/ or football/ or golf/ or gymnastics/ or hockey/ or jogging/ or martial arts/ or mountaineering/ or racquet sports/ or return to sport/ or running/ or skating/ or skiing/ or snow sports/ or soccer/ or sports/ or swimming/ or tai ji/ or tennis/ or "track and field"/ or volleyball/ or water sports/ or weight lifting/ or wrestling/ or youth sports/
11	(athlet* or baseball or basketball or bicycling or boxing or dance* or diving or football or golf or gymnastics or hockey or jogging or martial arts or mountaineering or racquet sports or running or skating or skiing or soccer or sport or sports or swimming or tai ji or tennis or track or volleyball or weight lifting or wrestling).ti,ab,kw,ci. or (return adj3 (performance or play or sport or sports)).ti,ab.
12	military medicine/ or naval medicine/ or submarine medicine/
13	Military Personnel/
14	(air force or army or coast guard or marines or military or naval or navy or sailor* or soldier*).ti,ab,kw,ci.
15	10 or 11 or 12 or 13 or 14
16	9 and 15
17	"Return to Sport"/ or (clear or cleared or return*).ti,ab,kw.
18	Reoperation/

19	(graft failure* or reinjur* or revision*).ti,ab,kw.
20	17 or 18 or 19
21	16 and 20
22	cohort studies/ or longitudinal studies/ or follow-up studies/ or prospective studies/ or retrospective studies/ or cohort.ti,ab,kw. or longitudinal.ti,ab,kw. or prospective.ti,ab,kw.
23	Case-Control Studies/ or Control Groups/ or Matched-Pair Analysis/ or ((case* adj5 control*) or (case adj3 comparison*) or control group*).ti,ab.
24	Cross-Sectional Studies/ or Prevalence/ or ((association adj2 (studies or study)) or cross-sectional or prevalence or transversal).ti,ab,kw. or (association or associations).ti.
25	("adaptive clinical trial" or "clinical trial" or "clinical trial, phase i" or "clinical trial, phase ii" or "clinical trial, phase iii" or "clinical trial, phase iv" or "controlled clinical trial" or "multicenter study" or "randomized controlled trial").pt. or double-blind method/ or "clinical trials as topic"/ or "clinical trials, phase i as topic"/ or "clinical trials, phase ii as topic"/ or "clinical trials, phase iii as topic"/ or "clinical trials, phase iv as topic"/ or "controlled clinical trials as topic"/ or "non-randomized controlled trials as topic"/ or "Equivalence Trials as Topic"/ or "Intention to Treat Analysis"/ or "Pragmatic Clinical Trials as Topic"/ or randomized controlled trials as topic/ or early termination of clinical trials as topic/ or multicenter studies as topic/ or ("phase I" or "phase II" or "phase III" or "phase IV" or "phase 1" or "phase 2" or "phase 3" or "phase 4").ti,ab,kw. or ((randomi?ed adj7 trial*) or (controlled adj3 trial*) or (clinical adj2 trial*) or ((single or doubl* or tripl* or treb*) and (blind* or mask*))).ti,ab,kw. or ("4 arm" or "four arm").ti,ab,kw.
26	prognosis/ or treatment outcome/ or treatment failure/ or (prognosis or prognostic*).ti,ab,kw.
27	evaluation study.pt.
28	"sensitivity and specificity"/ or "predictive value of tests"/ or (predictive or reliability or sensitivity or validity).ti,ab,kw.
29	(test battery or testing or tests).ti,ab,kw.
30	22 or 23 or 24 or 25 or 26 or 27 or 28 or 29
31	21 and 30
32	31 and english.la.
33	32 not (exp "Animals"/ not (exp "Animals"/ and "Humans"/))
34	33 not (exp child/ not (exp child/ and (adolescent/ or exp adult/)))
	UPDATE 1: January 6, 2021
35	(202006* or 202007* or 202008* or 202009* or 20201* or 2021*).dt,ez,da.
36	34 and 35
	UPDATE 2: January 27, 2022
35	(202101* or 202102* or 202103* or 202104* or 202105* or 202106* or 202107* or 202108* or 202109* or 20211* or 202201*).dt,ez,da.
36	34 and 35
37	36 not (23396461 or 26535266 or 30021073 or 30419175 or 1554072 or 8947392 or 8198189 or 15466722 or 22962296 or 27743080 or 22767478 or 15756616 or 1835965 or 33244476 or 30413858 or 32396470 or 22018321 or 20401753 or 31470759 or 30227449 or 33010751 or 27261476 or 30377716 or 33083169 or 25261222 or 25248310 or 26672024 or 25325560 or 12851350 or 15466760 or 25497145 or 1997243 or 3985258 or 8129110 or 22814219 or 30238238 or 25434851 or 29401330 or 32561136 or 32770983 or 25293342 or 22695136 or 21946441 or 23733635 or 25583757 or 20362824 or 21098818 or 2743663 or 33373534 or 33110693 or 31875070 or 33197876 or 10750992 or 29924719 or 30038828 or 28224443 or

	30267186 or 29399588 or 30984558 or 9784817 or 31895299 or 31840033 or 28050535 or 24914032 or 24770982 or 11819020 or 33064807 or 31486916 or 32932122 or 29395549 or 31205962 or 26524090 or 29791924 or 33339540 or 32374646 or 22137326 or 22030946 or 9240986 or 9934424 or 30554909 or 30820606 or 32504178 or 32647734 or 2380216 or 16009990 or 28268001 or 27146667 or 17932401 or 31633995 or 30839479 or 30534382 or 30361988 or 20842771 or 32005095 or 29032484 or 31095401 or 32747068 or 24568229 or 24905666 or 10223265 or 18385980 or 27792218 or 23288745 or 31439458 or 8819240 or 32128315 or 25540298 or 30844991 or 28217573 or 9642704 or 31821294 or 22467065 or 24783969 or 9167814 or 30024344 or 9240991 or 21773830 or 10148033 or 31756121 or 29678170 or 29169096 or 30481480 or 24676789 or 32025764 or 2285092 or 32266341 or 15581760 or 32067570 or 29552573 or 24836173 or 26311445 or 21813442 or 22869626 or 20632987 or 25633606 or 33195715 or 19472959 or 29136255 or 29762116 or 33294473 or 23002201 or 24768343 or 28840156 or 1418209 or 31004279 or 31782065 or 30315365 or 28875272 or 16952731 or 30712009 or 32702111 or 29847160 or 31590123 or 29505304 or 29707595 or 26276093 or 19664500 or 27347872 or 7573647 or 8261517 or 27894146 or 31803786 or 25404615 or 31413963 or 29575090 or 27859527 or 31289039 or 28224442 or 31042301 or 16870822 or 23449057 or 32984423 or 22261429 or 28116102 or 33010802 or 24794571 or 33165267 or 32368935 or 27035929 or 28273424 or 24145725 or 16131676 or 29963374 or 10217233 or 33330733 or 28817645 or 32010729 or 15743843 or 581286 or 27359295 or 26797700 or 19047767 or 19188897 or 30755561 or 29152521 or 27069948 or 27103604 or 8077261 or 28680893 or 25899211 or 30472490 or 16341690 or 30899542 or 8883695 or 16392446 or 30645948 or 28836467 or 21643922 or 31065554 or 30014185 or 2929838 or 8427353 or 28810991 or 29980379 or 32155933 or 24335588 or 9465566 or 26999412 or 26205774 or 28919498 or 32693626 or 32167837 or 25870471 or 30007063 or 25148470 or 19534296 or 31354961 or 7574323 or 7810787 or 25547235 or 26535351 or 28702921 or 32410697 or 31745732 or 30340128 or 10322588 or 21522223 or 18302729 or 31569256 or 29528481 or 12875565 or 32182102 or 32667824 or 28031496 or 30809722 or 30269166 or 28590374 or 23672381 or 21773828 or 31377824 or 23016064 or 25273364 or 29140169 or 8358918 or 20472756 or 18567717 or 32089965 or 32426400 or 30671490 or 9789847 or 24175599 or 23562809 or 32904857 or 32851108 or 33063128 or 28095169 or 25744596 or 27149566 or 31431339 or 29932875 or 27492688 or 29721458 or 24257662 or 27160462 or 27244126 or 15572320 or 20709944 or 32945776 or 2929826 or 10063808 or 10982658 or 31696135 or 30038825 or 28916871 or 30557764 or 1901971 or 11703036 or 30263898 or 27826598 or 31959673 or 31399428 or 32170357 or 26672476 or 6742302 or 20563560 or 23526315 or 2285086 or 26404563 or 32369839 or 25630243 or 31696134 or 26535359 or 26535238 or 26665248 or 24704069 or 25102509 or 9228311 or 23672380 or 24126701 or 31317214 or 15133583 or 25660011 or 27416993 or 26860104 or 32062685 or 24007758 or 26589671 or 28146394 or 25366191 or 30481050 or 24898528 or 26535286 or 26535272 or 31360732 or 984289 or 23138966 or 11950575 or 31375387 or 29456063 or 3621727 or 23132410 or 21710112 or 25274098 or 25174853 or 25653174 or 29669490 or 27167588 or 26994508 or 29147670 or 25100786 or 15716249 or 12528905 or 10654060 or 7778698 or 31728376 or 18523574 or 23906272 or 33283005 or 26490640 or 15911297 or 3661812 or 15483538 or 23624910 or 22928431 or 1831071 or 30690410 or 33384083 or 18354141 or 12368777 or 11194607 or 14966717 or 30196436 or 30733029 or 23744093 or 31743038 or 30730755 or 29634589 or 26535370 or 31526063 or 20347315 or 29931483 or 32388725 or 25318940 or 16458807 or 26491610 or 22389868 or 23474691 or 16628459 or 30253986 or 28707114 or 10346827 or 31092226 or 32147485 or 31940222 or 32871397 or 32944254 or 32002563 or 15603515 or 33112865 or 23238924 or 25201444 or 25973208 or 12098116 or 32309763 or 15756612 or 8465920 or 11914763 or 15156305 or 16496124 or 12966375 or 30398894 or 23371473 or 24563391 or 26720104 or 21511738 or 25311052 or 29209517 or 28428033 or 27423208 or 1395249 or 31511952 or 23593546 or 11288010 or

	32979819 or 1637437 or 24619491 or 24169301 or 20360607 or 32737527 or 26972570 or 26062956 or 31324964 or 28451617 or 32392085 or 29787697 or 31041331 or 25663423 or 25100769 or 22962290 or 23645830 or 32046955 or 27162233 or 27873020 or 20802815 or 26588108 or 27161867 or 31045665 or 28696164 or 31225999 or 25274353 or 31516911 or 29543512 or 31917613 or 29453931 or 16790541 or 26821962 or 31061594 or 28969952 or 31673172 or 32850031 or 30782075 or 29138919 or 27511467 or 31156767 or 420388 or 25047161 or 28899822 or 29158959 or 23016018 or 27530387 or 29659299 or 22560484 or 26740958 or 28203600 or 31158740 or 28349161 or 27733087 or 30041951 or 27539403 or 32715719 or 27460554 or 17146311 or 24679194 or 24427434 or 31637269 or 31678754 or 28548611 or 20195019 or 24175594 or 22983930 or 15711676 or 26035856 or 11918033 or 27855310 or 11409242 or 3752360 or 31071659 or 30476437 or 18067526 or 24158448 or 19851754 or 30038829 or 28523340 or 25724802 or 30124562 or 33386882 or 31739784 or 28969821 or 23041233 or 28817414 or 3674267 or 25749655 or 25682164 or 23052117 or 32009204 or 20215579 or 19225757 or 20507623 or 27379789 or 30300073 or 31629331 or 30008057 or 22265043 or 11371810 or 3881718 or 1490218 or 27717626 or 3667644 or 30526256 or 26637285 or 8666598 or 21344230 or 31506078 or 33388942 or 15496998 or 31211150 or 30211246 or 10663320 or 32322949 or 18237702 or 15800520 or 23395116 or 32659816 or 26231149 or 28917521 or 15057108 or 28918506 or 30770031 or 31173697 or 26359376 or 28644677 or 31373856 or 30772182 or 30446784 or 32761919 or 27163899 or 24075101 or 12435658 or 12544159 or 10591941 or 7768652 or 20434668 or 14629935 or 27671473 or 32051777 or 28383436 or 29404654 or 27159313 or 8998862 or 32741328 or 18298399 or 29394877 or 28383764 or 25559582 or 4051704 or 25212216 or 33344032 or 27104060 or 33128116 or 27483559 or 25899429 or 28847572 or 24981340 or 20709943 or 23703520 or 1962709 or 31136725 or 21088463 or 16877601 or 7810790 or 20526848 or 27903590 or 29332225 or 10810475 or 11706731 or 17322130 or 30386997 or 20051501 or 28624854 or 26493338 or 19952257 or 19352236 or 26971105 or 32343596 or 33150190 or 26545616 or 33283004 or 31989533 or 29900181 or 29769139 or 6548090 or 23523126 or 30943079 or 32031870 or 18802234 or 32563035 or 31679068 or 33118063 or 7880347 or 28378137 or 26694845 or 25112209 or 29383441 or 30148163 or 29975275 or 26919625 or 26952121 or 25646363 or 24890781 or 22467124 or 22570851 or 24961443 or 31743222 or 26255134 or 29290539 or 30729144 or 28210790 or 23032584 or 24622910 or 18308180 or 33370438 or 31042614 or 17700373 or 29854861 or 30090830 or 33276891 or 15168083 or 15703963 or 24746404 or 22257241 or 27215935 or 29954028 or 29059108 or 29767271 or 21112824 or 20219437 or 28223305 or 31084492 or 11447546 or 33044870 or 19019910 or 19374299 or 29286965 or 9486328 or 1781497 or 25461435 or 26996346 or 26075142 or 1937724 or 30640514 or 31402225 or 30115591 or 18461210 or 26933657 or 27530413 or 28054146 or 31215200 or 31215201 or 26768744 or 29114625 or 8407036 or 30763887 or 25950536 or 25480833 or 22951437 or 26471854 or 23069653 or 25819154 or 26981039 or 32637429 or 25315084 or 28822956 or 11779647 or 27485123 or 31807603 or 22495290 or 30702461 or 22021585 or 25239170 or 27289278 or 24667942 or 33389730 or 29550413 or 21800165 or 18974970 or 22562791 or 31633994 or 15846618 or 29309971 or 28680894 or 29364048 or 27343215 or 33010748 or 19279222 or 25347228 or 22349604 or 17761605 or 32379980 or 18796997 or 31063403 or 30501385 or 30439727 or 9006684 or 25466410 or 23881894 or 31487229 or 15031696 or 8526275 or 21138589 or 23772342 or 30237056 or 30401510 or 25261286 or 31307221 or 27480978 or 30193087 or 33165632 or 16411138 or 24687269 or 28510477 or 12444509 or 26378269 or 25727493 or 22262420 or 24945476 or 18780998 or 26100299 or 15800528 or 24214928 or 8600736 or 12548444 or 23111744 or 11536088 or 6897496 or 24140144 or 3652576 or 33380982 or 31531768 or 30361837 or 11154372 or 21660595 or 20810093 or 22048746 or 15611003 or 30077268 or 25537942 or 9131235 or 32733975 or 29782440 or 28463928 or 25868636 or 15480713 or 3278634 or 8902129 or 27737288 or 27231334 or 22922520 or 7391092 or 15572317 or 27900339 or

	28255567 or 31373377 or 30786247 or 30753794 or 24001575 or 21519299 or 29284175 or 27294169 or 27620968 or 29895233 or 12793556 or 30547044 or 21886009 or 32452208 or 23739685 or 29318168 or 31030253 or 11147151 or 31034636 or 28992770 or 12528909 or 26801923 or 27720633 or 10798788 or 27159316 or 7593101 or 2910924 or 23864175 or 29028445 or 18979658 or 20959698 or 27039329 or 22915498 or 26759030 or 10442619 or 33389731 or 28506133 or 19439759 or 30274539 or 25124481 or 25178537 or 20511035 or 24740666 or 12734710 or 22116668 or 22207028 or 22879403 or 18438211 or 15535356 or 21289456 or 30090673 or 28451615 or 15728687 or 28107551 or 14623667 or 33344017 or 32402078 or 31025059 or 25894748 or 30905996 or 33150192 or 27402457 or 31195246 or 30747746 or 7790479 or 21378485 or 22163095 or 8775705 or 12002492 or 28954801 or 28125899 or 15944625 or 16477472 or 8905107 or 8044490 or 29927499 or 31901699 or 31409425 or 32547976 or 33079573 or 31408765 or 15018185 or 21290118 or 29900180 or 26675061 or 11101098 or 31656192 or 24239107 or 8836351 or 29485941 or 2071620 or 1522103 or 8427363 or 9397264 or 9302467 or 9276055 or 11507120 or 15722278 or 16365373 or 22074619 or 28449611 or 28727937 or 31272646 or 28463915 or 24198553 or 17084301 or 28154888 or 32699921 or 31877093 or 30109947 or 8666597 or 12861215 or 24815055 or 32953922 or 29550753 or 30611344 or 28451611 or 29032903 or 28481383 or 9641438 or 29909296 or 29279562 or 20111955 or 19838671 or 30995103 or 1456360 or 31797020 or 22534281 or 31194624 or 27217932 or 26408992 or 31648996 or 25192689 or 22688502 or 8129109 or 33144236 or 22713252 or 31027121 or 31321592 or 30882565 or 30531545 or 29272209 or 17620778 or 29318172 or 22343967 or 24753238 or 23219783 or 21808100 or 20702858 or 3733814 or 2729495 or 12544156 or 18796852 or 16210575 or 20829416 or 31404758 or 30376512 or 31555717 or 31763340 or 25091127 or 23604790 or 16798991 or 29164130 or 20160630 or 31170646 or 16958481 or 12860552 or 31887765 or 32426142 or 31555843 or 27817976 or 25512664 or 31990575 or 33356796 or 30534573 or 31563991 or 30649904 or 30481831 or 30543272 or 6742301 or 17468379 or 23153663 or 27519675 or 32590844 or 32396964 or 28667211 or 31589465 or 32132445 or 28706842 or 30473373 or 33096577 or 32268406 or 28467122 or 32522734 or 33150442 or 32293904 or 30292594 or 22951370 or 26165552 or 12522394 or 27712856 or 29377306 or 22942168 or 17578979 or 29243827 or 33158001 or 24619794 or 8734879 or 16502300 or 27581178 or 26234028 or 26727827 or 30209520 or 30418218 or 25997812 or 32032156 or 15773563 or 25538479 or 1443318 or 30704884 or 33195714 or 30135871 or 28095091 or 30827441 or 29675503 or 31297583 or 9474408 or 24519183 or 33386427 or 21874942 or 26015599 or 30574516 or 23212189 or 31089791 or 31295302 or 31233335 or 16084292 or 29244525 or 28272928 or 25266230 or 19801293 or 28714793 or 26920430 or 31439457 or 33332148 or 24861490 or 17065935 or 30078121 or 9826803 or 10492030 or 31709890 or 10220847 or 17539208 or 16143872 or 2148610 or 29478904 or 28298067 or 26743422 or 24634094 or 30719479 or 25373481 or 22813542 or 27465632 or 32547970 or 29511817 or 29854864 or 3755440 or 27498106 or 28638970 or 28498226 or 3377102 or 31254917 or 26003872 or 26158388 or 27033842 or 1550653 or 15243454 or 2405722 or 20434665 or 20610771 or 29600266 or 11912091 or 29991077 or 24627577 or 8600735 or 9397266 or 19109531 or 15262645 or 12721340 or 8526273 or 2372081 or 8800538 or 23015878 or 11032219 or 2252089 or 8238708 or 9302471 or 1867333 or 3578633 or 12734717 or 16758236 or 9586972 or 26667371 or 19288080 or 28941959 or 28787229 or 22570882 or 17478276 or 4028570 or 27079625 or 30394202 or 31339475 or 32119785 or 31479009 or 32079913 or 31775553 or 15155426 or 24457384 or 32059954 or 30879108 or 9079172 or 24682517 or 2039067 or 30733624 or 27562372 or 25203652 or 28608009 or 28151693 or 25740835 or 24149555 or 26205480 or 31835112 or 21084660 or 22912340 or 32679296 or 6705125 or 21046300 or 31689685 or 23016104 or 16468488 or 23425687 or 31864576 or 26069601 or 23974633 or 27590175 or 31286929 or 31903405 or 30577053 or 29164167 or 29466066 or 32512505 or 29780839 or 27733884 or 26539442 or 4015018 or 30374568 or 31924236 or

	28363421 or 26122667 or 27514942 or 26559443 or 16501976 or 25802119 or 30068011 or 30988109 or 24381943 or 26875053 or 33306441 or 19578485 or 29305288 or 32471051 or 31883855 or 31879792 or 30790527 or 16774652 or 18034333 or 21932078 or 22314862 or 26048896 or 701338 or 29526409 or 29511820 or 23015924 or 32629513 or 31598410 or 28056178 or 28251262 or 28990491 or 32734333 or 30534575 or 32984422 or 19460815 or 29700560 or 24529851 or 33317636 or 16878827 or 33386881 or 11665745 or 27553297 or 9339619 or 26105017 or 420386 or 22008978 or 24120924 or 16235457 or 28803759 or 28194829 or 21311861 or 22238055 or 23380160 or 23685095 or 20069277 or 28676083 or 27539507 or 30259146 or 21654455 or 26831862 or 32874110 or 32303448 or 22465979 or 30797544 or 20934698 or 30906128 or 10525702 or 22282347 or 22298053 or 25455185 or 20532869 or 27034129 or 28451597 or 26790801 or 21664792 or 32915640 or 10102100 or 26131297 or 29552571 or 22465899 or 9546463 or 21062181 or 24934927 or 23708380 or 27390346 or 28718171 or 30116761 or 29662909 or 30649903 or 31431901 or 26578718 or 29516122 or 29382207 or 30525891 or 19083699 or 24451111 or 28473996 or 30905035 or 32259646 or 31628097 or 31381373 or 29718684 or 19336620 or 25917066 or 31425918 or 32247810 or 29549389 or 29574548 or 19568022 or 28355978 or 31996981 or 29775379 or 31431898 or 30878328 or 10627345 or 30090672 or 23522373 or 25685823 or 33332154 or 25522680 or 31734844 or 22738187 or 27778041 or 10512210 or 16646628 or 22382825 or 7920603 or 15342756 or 15773040 or 12568260 or 31693388 or 2355037 or 27728954 or 2343983 or 11216716 or 8536011 or 29602303 or 22303759 or 21776554 or 31741480 or 25481088 or 27871656 or 26131298 or 30827423 or 18045513 or 33098948 or 27734019 or 16845548 or 23329075 or 31123921 or 21885909 or 32957304 or 27837221 or 32809855 or 20668835 or 18208432 or 29032309 or 24593869 or 30083970 or 16909301 or 28922015 or 29270546 or 3594987 or 30053791 or 32741329 or 29669497 or 16517309 or 28125675 or 26183172 or 27257127).ui.

Appendix B.1.2 Embase® Search Strategy

Supplemental Table 7: Embase® Search Strategy

Provider/Interface	Elsevier
Database	Embase®
Date searched	June 8, 2020; Update 1: January 6, 2021; Update 2: January 27, 2022
Database update	June 8, 2020; Update 1: January 6, 2021; Update 2: January 27, 2022
Search developer(s)	Helena M. VonVille
Limit to English	Yes
Date Range	No date limitations set
Publication Types	Excluded conference abstracts, conference papers, conference reviews, and editorials
Search filter source	No search filter used

#1	'anterior cruciate ligament reconstruction'/de
#2	anterior cruciate ligament'/de OR 'anterior cruciate ligament injury'/de OR 'anterior cruciate ligament rupture'/de
#3	acl':ti,ab,kw or 'anterior cruciate ligament':ti,ab,kw
#4	#2 OR #3
#5	orthopedic surgery'/de OR 'knee ligament surgery'/de OR 'arthroplasty'/de OR 'knee arthroplasty'/de
#6	arthroplast*':ti,ab,kw or 'graft*':ti,ab,kw or 'orthopedic*':ti,ab,kw or 'reconstruction':ti,ab,kw or 'repair*':ti,ab,kw or 'surgery':ti,ab,kw or 'surgical':ti,ab,kw or 'transplant*':ti,ab,kw
#7	surgery':lnk
#8	#5 OR #6 OR #7
#9	(#4 AND #8) OR #1
#10	athlete'/de OR 'ball sports athlete'/de OR 'baseball player'/de OR 'basketball player'/de OR 'body builder'/de OR 'boxer'/de OR 'collision athlete'/de OR 'combat sports athlete'/de OR 'contact athlete'/de OR 'cyclist'/de OR 'disabled athlete'/de OR 'elite athlete'/de OR 'endurance athlete'/de OR 'football player'/de OR 'gymnast'/de OR 'hockey player'/de OR 'judoka'/de OR 'lacrosse player'/de OR 'marathon runner'/de OR 'professional athlete'/de OR 'runner'/de OR 'skier'/de OR 'soccer player'/de OR 'softball player'/de OR 'squash player'/de OR 'student athlete'/de OR 'triathlete'/de OR 'wrestler'/de
#11	('athlet*':ti,ab,kw OR 'baseball':ti,ab,kw OR 'basketball':ti,ab,kw OR 'bicycling':ti,ab,kw OR 'body builder':ti,ab,kw OR 'boxing':ti,ab,kw OR 'boxer*':ti,ab,kw OR 'cyclist'/exp OR 'dance*':ti,ab,kw OR 'diving':ti,ab,kw OR 'football':ti,ab,kw OR 'golf':ti,ab,kw OR 'gymnastics':ti,ab,kw OR 'hockey':ti,ab,kw OR 'jogging':ti,ab,kw OR 'judoka':ti,ab,kw OR 'lacrosse':ti,ab,kw OR 'marathon':ti,ab,kw OR 'martial arts':ti,ab,kw OR 'mountaineering':ti,ab,kw OR 'racquet sports':ti,ab,kw OR 'running':ti,ab,kw OR 'skating':ti,ab,kw OR 'skier*':ti,ab,kw OR 'skiing':ti,ab,kw OR 'soccer':ti,ab,kw OR 'sport':ti,ab,kw OR 'sports':ti,ab,kw OR 'swimming':ti,ab,kw OR 'tai ji':ti,ab,kw OR 'tennis':ti,ab,kw OR 'track':ti,ab,kw OR 'triathlet*':ti,ab,kw OR 'volleyball':ti,ab,kw OR 'weight lifting':ti,ab,kw OR 'wrestling':ti,ab,kw) OR ('return' NEAR/3 ('performance' OR 'play' OR 'sport' OR 'sports'))
#12	military medicine'/exp OR 'military personnel'/de

#13	('air force':ti,ab,kw OR 'army':ti,ab,kw OR 'coast guard':ti,ab,kw OR 'marines':ti,ab,kw OR 'military':ti,ab,kw OR 'naval':ti,ab,kw OR 'navy':ti,ab,kw OR 'sailor*':ti,ab,kw OR 'soldier*':ti,ab,kw) OR ('return' NEAR/3 ('active' OR 'duty'))
#14	#10 OR #11 OR #12 OR #13
#15	#9 AND #14
#16	return to sport'/de
#17	graft failure'/de
#18	reoperation'/de
#19	clear':ti,ab,kw OR 'cleared':ti,ab,kw OR 'return*':ti,ab,kw
#20	#16 OR #17 OR #18 OR #19
#21	#15 AND #20
#22	('case control study'/de OR 'cohort analysis'/de OR 'comparative effectiveness'/de OR 'comparative study'/de OR 'control group'/de OR 'controlled clinical trial'/de OR 'controlled clinical trial'/de OR 'controlled study'/de OR 'correlational study'/de OR 'cross-sectional study'/de OR 'double blind procedure'/de OR 'equivalence trial'/de OR 'experimental design'/de OR 'experimental study'/de OR 'exploratory research'/de OR 'factorial design'/de OR 'feasibility study'/de OR 'field study'/de OR 'forced choice method'/de OR 'grounded theory'/de OR 'intention to treat analysis'/de OR 'intermethod comparison'/de OR 'magnitude estimation method'/de OR 'meta analysis (topic)'/de OR 'methodology'/de OR 'multicenter study'/de OR 'multimethod study'/de OR 'nonequivalent control group'/de OR 'non-inferiority trial'/de OR 'observational study'/de OR 'pilot study'/de OR 'population based case control study'/de OR 'practice guideline'/de OR 'pragmatic trial'/de OR 'pretest posttest control group design'/de OR 'pretest posttest control group design'/de OR 'pretest posttest design'/de OR 'prevalence'/de OR 'prevention study'/de OR 'quality improvement study'/de OR 'quasi experimental study'/de OR 'randomized controlled trial'/de OR 'replication study'/de OR 'secondary analysis'/de OR 'single blind procedure'/de OR 'static group comparison'/de OR 'study design'/de OR 'superiority trial'/de OR 'theoretical study'/de OR 'trend study'/de OR 'twin study'/de OR 'validation study'/de)
#23	sensitivity and specificity'/de
#24	('adverse outcome'/de OR 'clinical outcome'/de OR 'disease free interval'/de OR 'evaluation and follow up'/de OR 'evaluation study'/de OR 'functional assessment'/de OR 'GRADE approach'/de OR 'minimal clinically important difference'/de OR 'outcome assessment'/de OR 'outcomes research'/de OR 'patient-reported outcome'/de OR 'prediction and forecasting'/de OR 'predictive value'/de OR 'prognosis'/de OR 'treatment failure'/de OR 'treatment outcome'/de OR 'unexpected therapeutic effect'/de)
#25	('predictive':ti,ab,kw OR 'reliability':ti,ab,kw OR 'sensitivity':ti,ab,kw OR 'validity':ti,ab,kw OR 'test battery':ti,ab,kw OR 'testing':ti,ab,kw OR 'tests':ti,ab,kw OR 'clinical trial*':ti,ab,kw OR 'cross-sectional':ti,ab,kw OR 'cohort':ti,ab,kw OR 'longitudinal':ti,ab,kw OR 'prospective':ti,ab,kw OR 'follow-up':ti,ab,kw OR 'association':ti,ab,kw OR 'associations':ti,ab,kw OR 'transversal':ti,ab,kw)
#26	#22 OR #23 OR #24 OR #25
#27	#21 AND #26
#28	#27 AND [english]/lim
#29	#28 NOT ([school]/lim NOT ([school]/lim AND ([adolescent]/lim OR [young adult]/lim OR [adult]/lim OR [middle aged]/lim)
#30	#29 AND ([conference abstract]/lim OR [conference paper]/lim OR [conference review]/lim OR [editorial]/lim)

#31	#29 NOT #30
	Update 1: **January 6, 2021**
#32	[8-6-2020]/sd AND #31
#33	#32 NOT (33389731:ui OR 33389730:ui OR 33388942:ui OR 33386882:ui OR 33386881:ui OR 33386427:ui OR 33384083:ui OR 33197876:ui OR 32522734:ui OR 33373534:ui OR 33370438:ui OR 33356796:ui OR 33098948:ui OR 33096577:ui OR 33306441:ui OR 33332154:ui OR 33332148:ui OR 33144236:ui OR 33165632:ui OR 33165267:ui OR 33150442:ui OR 33118063:ui OR 33064807:ui OR 33044870:ui OR 32809855:ui OR 32761919:ui OR 32737527:ui OR 32734333:ui OR 32715719:ui OR 32659816:ui OR 32629513:ui OR 32561136:ui OR 33380982:ui OR 33339540:ui OR 33344032:ui OR 33344017:ui OR 33330733:ui OR 33317636:ui OR 32871397:ui OR 32679296:ui OR 33294473:ui OR 33283005:ui OR 33283004:ui OR 32590844:ui OR 33244476:ui OR 33195715:ui OR 33195714:ui OR 32979819:ui OR 32932122:ui OR 33010751:ui OR 33010748:ui OR 32915640:ui OR 33150192:ui OR 33150190:ui OR 32741329:ui OR 32741328:ui OR 33128116:ui OR 33110693:ui OR 32699921:ui OR 33083169:ui OR 33063128:ui OR 32945776:ui OR 33010802:ui OR 32504178:ui OR 32984423:ui OR 32984422:ui OR 32953922:ui OR 32944254:ui OR 32904857:ui OR 32851108:ui OR 32850031:ui OR 32733975:ui OR 32647734:ui OR 32637429:ui OR 32563035:ui OR 32770983:ui OR 32508385:ui OR 33079573:ui OR 32702111:ui OR 32396470:ui OR 32067570:ui OR 33276891:ui OR 32874110:ui OR 33112865:ui OR 32512505:ui OR 32247810:ui OR 31679068:ui OR 33158001:ui OR 32229741:ui OR 32374646:ui OR 32667824:ui OR 31612316:ui OR 32693626:ui OR 32452208:ui OR 32182102:ui OR 32119785:ui OR 31317214:ui OR 31990575:ui OR 31996981:ui OR 32046955:ui OR 32957304:ui OR 32396964:ui OR 32402078:ui OR 32747068:ui OR 31954959:ui OR 31940222:ui OR 31917613:ui OR 31089791:ui OR 31025059:ui OR 30882565:ui OR 32379980:ui OR 32368935:ui OR 32343596:ui OR 31743038:ui OR 31479009:ui OR 31531768:ui OR 31797020:ui OR 31555843:ui OR 31377824:ui OR 31959673:ui OR 31312875:ui OR 31324964:ui OR 31678754:ui OR 32132445:ui OR 32028474:ui OR 32005095:ui OR 32547976:ui OR 32547970:ui OR 31404758:ui OR 31408765:ui OR 31470759:ui OR 31511952:ui OR 31633995:ui OR 30759359:ui OR 31693388:ui OR 31633994:ui OR 30419175:ui OR 31589465:ui OR 31195246:ui)
	UPDATE 2: January 27, 2022
#32	[6-1-2021]/sd AND #31
#33	#32 NOT (30855342:ui OR 31334763:ui OR 31476778:ui OR 31962350:ui OR 31975356:ui OR 32240345:ui OR 32240346:ui OR 32544974:ui OR 32555088:ui OR 32673067:ui OR 32699920:ui OR 32872688:ui OR 32898426:ui OR 32937005:ui OR 33160279:ui OR 33261305:ui OR 33333268:ui OR 33417046:ui OR 33418539:ui OR 33419913:ui OR 33429149:ui OR 33452381:ui OR 33452577:ui OR 33452579:ui OR 33457435:ui OR 33463428:ui OR 33482621:ui OR 33483768:ui OR 33483769:ui OR 33485163:ui OR 33486409:ui OR 33487103:ui OR 33500748:ui OR 33515391:ui OR 33517476:ui OR 33521157:ui OR 33523751:ui OR 33530847:ui OR 33550916:ui OR 33553449:ui OR 33553459:ui OR 33556590:ui OR 33560866:ui OR 33566239:ui OR 33586624:ui OR 33604144:ui OR 33604148:ui OR 33614794:ui OR 33614803:ui OR 33615247:ui OR 33617286:ui OR 33617291:ui OR 33620511:ui OR 33626438:ui OR 33630656:ui OR 33650704:ui OR 33656379:ui OR 33656938:ui OR 33677631:ui OR 33681400:ui OR 33681401:ui OR 33687926:ui OR 33687928:ui OR 33689510:ui OR 33709206:ui OR 33714927:ui OR 33718503:ui OR 33720764:ui OR 33735637:ui OR 33736965:ui OR 33738307:ui OR 33738820:ui OR 33748298:ui OR 33756262:ui OR 33764229:ui OR

	33765648:ui OR 33782638:ui OR 33784786:ui OR 33793363:ui OR 33795964:ui OR 33796963:ui OR 33809935:ui OR 33810610:ui OR 33811490:ui OR 33827671:ui OR 33830821:ui OR 33834527:ui OR 33836820:ui OR 33842052:ui OR 33844590:ui OR 33846157:ui OR 33856914:ui OR 33865216:ui OR 33865217:ui OR 33876272:ui OR 33878493:ui OR 33885946:ui OR 33889639:ui OR 33889640:ui OR 33892073:ui OR 33894653:ui OR 33896240:ui OR 33896493:ui OR 33899128:ui OR 33910466:ui OR 33930209:ui OR 33931067:ui OR 33932294:ui OR 33936951:ui OR 33940305:ui OR 33951223:ui OR 33954220:ui OR 33957214:ui OR 33970295:ui OR 33971578:ui OR 33978778:ui OR 33997075:ui OR 33997461:ui OR 33999877:ui OR 34001504:ui OR 34006272:ui OR 34006577:ui OR 34009463:ui OR 34017876:ui OR 34027455:ui OR 34038185:ui OR 34081370:ui OR 34088854:ui OR 34091057:ui OR 34104662:ui OR 34116406:ui OR 34123520:ui OR 34124374:ui OR 34126566:ui OR 34129680:ui OR 34138788:ui OR 34157148:ui OR 34187258:ui OR 34189080:ui OR 34195652:ui OR 34195659:ui OR 34206782:ui OR 34226016:ui OR 34236927:ui OR 34251870:ui OR 34259599:ui OR 34259606:ui OR 34260290:ui OR 34268383:ui OR 34276409:ui OR 34283039:ui OR 34300065:ui OR 34310176:ui OR 34321559:ui OR 34325524:ui OR 34329413:ui OR 34351825:ui OR 34360344:ui OR 34383156:ui OR 34386283:ui OR 34386285:ui OR 34386294:ui OR 34388652:ui OR 34409112:ui OR 34422294:ui OR 34423062:ui OR 34425491:ui OR 34435067:ui OR 34441865:ui OR 34450783:ui OR 34459955:ui OR 34475613:ui OR 34486440:ui OR 34492443:ui OR 34530211:ui OR 34541010:ui OR 34554253:ui OR 34568996:ui OR 34571186:ui OR 34590928:ui OR 34604424:ui OR 34604426:ui OR 34623431:ui OR 34623936:ui OR 34623939:ui OR 34623948:ui OR 34631248:ui OR 34631250:ui OR 34643475:ui OR 34646893:ui OR 34651507:ui OR 34662420:ui OR 34674738:ui OR 34676273:ui OR 34692877:ui OR 34700261:ui OR 34708138:ui OR 34708141:ui OR 34711502:ui OR 34712986:ui OR 34717094:ui OR 34717774:ui OR 34723674:ui OR 34739559:ui OR 34742028:ui OR 34746844:ui OR 34762143:ui OR 34768111:ui OR 34778471:ui OR 34778482:ui OR 34778483:ui OR 34778484:ui OR 34782927:ui OR 34797936:ui OR 34839367:ui OR 34845153:ui OR 34846037:ui OR 34847471:ui OR 34857725:ui OR 34872076:ui OR 34877191:ui OR 34881338:ui OR 34889652:ui OR 34896962:ui OR 34898285:ui OR 34903114:ui OR 34905939:ui OR 34909247:ui OR 34932514:ui OR 34939109:ui OR 34949606:ui OR 34956574:ui OR 34972552:ui OR 34977628:ui OR 35005045:ui OR 35005049:ui OR 35005053:ui OR 35039919:ui OR 35040694:ui OR 35050817:ui OR 35067605:ui OR 35079843:ui)
#34	#33 NOT (33389731:ui OR 33389730:ui OR 33388942:ui OR 33386882:ui OR 33386881:ui OR 33386427:ui OR 33384083:ui OR 33197876:ui OR 32522734:ui OR 33373534:ui OR 33370438:ui OR 33356796:ui OR 33098948:ui OR 33096577:ui OR 33306441:ui OR 33332154:ui OR 33332148:ui OR 33144236:ui OR 33165632:ui OR 33165267:ui OR 33150442:ui OR 33118063:ui OR 33064807:ui OR 33044870:ui OR 32809855:ui OR 32761919:ui OR 32737527:ui OR 32734333:ui OR 32715719:ui OR 32659816:ui OR 32629513:ui OR 32561136:ui OR 33380982:ui OR 33339540:ui OR 33344032:ui OR 33344017:ui OR 33330733:ui OR 33317636:ui OR 32871397:ui OR 32679296:ui OR 33294473:ui OR 33283005:ui OR 33283004:ui OR 32590844:ui OR 33244476:ui OR 33195715:ui OR 33195714:ui OR 32979819:ui OR 32932122:ui OR 33010751:ui OR 33010748:ui OR 32915640:ui OR 33150192:ui OR 33150190:ui OR 32741329:ui OR 32741328:ui OR 33128116:ui OR 33110693:ui OR 32699921:ui OR 33083169:ui OR 33063128:ui OR 32945776:ui OR 33010802:ui OR 32504178:ui OR 32984423:ui OR 32984422:ui OR 32953922:ui OR 32944254:ui OR 32904857:ui OR 32851108:ui OR 32850031:ui OR 32733975:ui OR 32647734:ui OR 32637429:ui OR 32563035:ui OR 32770983:ui OR 32508385:ui OR 33079573:ui OR 32702111:ui OR 32396470:ui OR 32067570:ui OR 33276891:ui OR 32874110:ui OR 33112865:ui OR 32512505:ui OR

	32247810:ui OR 31679068:ui OR 33158001:ui OR 32229741:ui OR 32374646:ui OR 32667824:ui OR 31612316:ui OR 32693626:ui OR 32452208:ui OR 32182102:ui OR 32119785:ui OR 31317214:ui OR 31990575:ui OR 31996981:ui OR 32046955:ui OR 32957304:ui OR 32396964:ui OR 32402078:ui OR 32747068:ui OR 31954959:ui OR 31940222:ui OR 31917613:ui OR 31089791:ui OR 31025059:ui OR 30882565:ui OR 32379980:ui OR 32368935:ui OR 32343596:ui OR 31743038:ui OR 31479009:ui OR 31531768:ui OR 31797020:ui OR 31555843:ui OR 31377824:ui OR 31959673:ui OR 31312875:ui OR 31324964:ui OR 31678754:ui OR 32132445:ui OR 32028474:ui OR 32005095:ui OR 32547976:ui OR 32547970:ui OR 31404758:ui OR 31408765:ui OR 31470759:ui OR 31511952:ui OR 31633995:ui OR 30759359:ui OR 31693388:ui OR 31633994:ui OR 30419175:ui OR 31589465:ui OR 31195246:ui)

Appendix B.1.3 CINAHL® search strategy

Supplemental Table 8: CINAHL® Search Strategy

Provider/Interface	Ebsco
Database	CINAHL®
Date searched	June 16, 2020; updated January 6, 2021
Database update	June 16, 2020; updated January 6, 2021
Search developer(s)	Helena M. VonVille
Limit to English	Yes
Date Range	No date limitations set
Publication Types	No publication type limitations set
Search filter source	

S1	(MH "Anterior Cruciate Ligament Reconstruction")
S2	(MH "Anterior Cruciate Ligament Injuries") OR (MH "Anterior Cruciate Ligament")
S3	TI (acl OR anterior cruciate ligament) OR AB (acl OR anterior cruciate ligament)
S4	S2 OR S3
S5	(MH "Surgery, Operative") OR (MH "Orthopedic Surgery") OR (MH "Arthroplasty")
S6	TI (arthroplast* or graft* or orthopedic* or reconstruction or repair* or surgery or surgical or transplant*) OR AB (arthroplast* or graft* or orthopedic* or reconstruction or repair* or surgery or surgical or transplant*)
S7	S5 OR S6
S8	S4 AND S7
S9	S1 OR S8
S10	"(MH ""Athletes"") OR (MH ""Athletes, Amateur"") OR (MH ""Athletes, College"") OR (MH ""Athletes, Disabled"") OR (MH ""Athletes, Elite"") OR (MH ""Athletes, Female"") OR (MH ""Athletes, High School"") OR (MH ""Athletes, Male"") OR (MH ""Athletes, Master"") OR (MH ""Athletes, Professional"") OR (MH ""Athletic Performance"") OR (MH ""Rehabilitation, Athletic"")
S11	(MH "Team Sports") OR (MH "Baseball") OR (MH "Basketball") OR (MH "Cricket (Sports)") OR (MH "Football") OR (MH "Hockey") OR (MH "Rugby") OR (MH "Soccer") OR (MH

	"Softball") OR (MH "Volleyball") OR (MH "Aquatic Sports") OR (MH "Diving") OR (MH "Rowing") OR (MH "Swimming") OR (MH "Water Skiing") OR (MH "Body Building") OR (MH "Bowling") OR (MH "Caving") OR (MH "College Sports") OR (MH "Contact Sports") OR (MH "Boxing") OR (MH "Martial Arts") OR (MH "Wrestling") OR (MH "Cycling") OR (MH "Endurance Sports") OR (MH "Extreme Sports") OR (MH "Fencing") OR (MH "Gymnastics") OR (MH "Golf") OR (MH "Handball") OR (MH "Motor Sports") OR (MH "Mountaineering") OR (MH "Race Walking") OR (MH "Racquet Sports") OR (MH "Tennis") OR (MH "Rock Climbing") OR (MH "Running") OR (MH "Jogging") OR (MH "Running, Distance") OR (MH "Sprinting") OR (MH "Skating") OR (MH "Ice Skating") OR (MH "Skateboarding") OR (MH "Skiing") OR (MH "Snow Skiing") OR (MH "Cross Country Skiing") OR (MH "Sports, Disabled") OR (MH "Target Sports") OR (MH "Archery") OR (MH "Track and Field") OR (MH "Triathlon") OR (MH "Weight Lifting") OR (MH "Snowboarding")
S12	TI (athlet* OR baseball OR basketball OR bicycling OR boxing OR dance* OR diving OR football OR golf OR gymnastics OR hockey OR jogging OR martial arts OR mountaineering OR racquet sports OR running OR skating OR skiing OR soccer OR sport OR sports OR swimming OR tai ji OR tennis OR track OR volleyball OR weight lifting OR wrestling) OR (return N3 (duty OR performance OR play OR sport OR sports)) OR AB (athlet* OR baseball OR basketball OR bicycling OR boxing OR dance* OR diving OR football OR golf OR gymnastics OR hockey OR jogging OR martial arts OR mountaineering OR racquet sports OR running OR skating OR skiing OR soccer OR sport OR sports OR swimming OR tai ji OR tennis OR track OR volleyball OR weight lifting OR wrestling) OR (return N3 (duty OR performance OR play OR sport OR sports))
S13	(MH "Military Medicine") OR (MH "Military Personnel") OR (MH "Active Duty Personnel") OR (MH "Enlisted Personnel") OR (MH "Reserve Personnel") OR (MH "Military Recruits") OR (MH "Military Services") OR (MH "United States Air Force") OR (MH "United States Army") OR (MH "United States Coast Guard") OR (MH "United States Marine Corps") OR (MH "United States Navy")
S14	TI (air force OR army OR coast guard OR marines OR military OR naval OR navy OR sailor* OR soldier*) OR AB (air force OR army OR coast guard OR marines OR military OR naval OR navy OR sailor* OR soldier*)
S15	S10 OR S11 OR S12 OR S13 OR S14
S16	S9 AND S15
S17	(MH "Sports Re-Entry")
S18	TI (clear OR cleared OR return*) OR AB *(clear OR cleared OR return*)
S19	(MH "Reoperation")
S20	TI (graft failure* OR reinjur* OR revision*) OR AB (graft failure* OR reinjur* OR revision*)
S21	S17 OR S18 OR S19 OR S20
S22	S16 AND S21
S23	(MH "Clinical Trials") OR (MH "Double-Blind Studies") OR (MH "Intervention Trials") OR (MH "Preventive Trials") OR (MH "Randomized Controlled Trials") OR (MH "Equivalence Trials") OR (MH "Single-Blind Studies") OR (MH "Therapeutic Trials") OR (MH "Triple-Blind Studies") OR (MH "Controlled Before-After Studies") OR (MH "Nonrandomized Trials") OR (MH "Pretest-Posttest Design") OR (MH "Pretest-Posttest Control Group Design") OR (MH "Crossover Design") OR (MH "Nonexperimental Studies") OR (MH "Case Control Studies") OR (MH "Hospital-Based Case Control") OR (MH "Matched Case Control") OR (MH "Population-Based Case Control") OR (MH "Cross Sectional Studies") OR (MH "Prospective Studies") OR (MH "Concurrent Prospective Studies") OR (MH "Nonconcurrent

	Prospective Studies") OR (MH "Nonequivalent Control Group") OR (MH "Quasi-Experimental Studies") OR (MH "Retrospective Design") OR (MH "Empirical Research")
S24	(MH "Sensitivity and Specificity") OR (MH "Prognosis") OR (MH "Treatment Outcomes") OR (MH "Treatment Failure") OR (MH "Therapeutic Index") OR (MH "Predictive Value of Tests") OR (MH "Measurement Issues and Assessments") OR (MH "Reliability and Validity")
S25	TI ("multicenter study" OR ((randomised OR randomized) N7 trial*) OR (controlled N3 trial*) OR (clinical N2 trial*) OR ((single OR doubl* OR tripl* OR treb*) N3 (blind* OR mask*)) OR "4 arm" OR "four arm") OR AB ("multicenter study" OR ((randomised OR randomized) N7 trial*) OR (controlled N3 trial*) OR (clinical N2 trial*) OR ((single OR doubl* OR tripl* OR treb*) N3 (blind* OR mask*)) OR "4 arm" OR "four arm")
S26	TI (cohort OR longitudinal OR prospective OR ((case OR cases) N5 control*) OR ((case OR cases) N3 comparison*) OR control group* OR predictive OR reliability OR sensitivity OR validity OR test battery OR testing OR tests) OR AB (cohort OR longitudinal OR prospective OR ((case OR cases) N5 control*) OR ((case OR cases) N3 comparison*) OR control group* OR predictive OR reliability OR sensitivity OR validity OR test battery OR testing OR tests)
S27	S23 OR S24 OR S25 OR S26
S28	S22 AND S27
S29	S28 Limiters - English Language
	UPDATE January 6, 2021
S30	S29 AND EM 20200616- Limiters - English Language

Appendix B.1.4 Non-database Searches Yielding New Studies

Bibliographies Searched:

1. Welling W, Benjaminse A, Lemmink K, et al. Passing return to sports tests after ACL reconstruction is associated with greater likelihood for return to sport but fail to identify second injury risk. *Knee* 2020;27(3):949-57. doi: 10.1016/j.knee.2020.03.007 [published Online First: 2020/04/06]
2. Raoul T, Klouche S, Guerrier B, et al. Are athletes able to resume sport at six-month mean follow-up after anterior cruciate ligament reconstruction? Prospective functional and psychological assessment from the French Anterior Cruciate Ligament Study (FAST) cohort. *Knee* 2019;26(1):155-64. doi: 10.1016/j.knee.2018.11.006 [published Online First: 2018/11/27]
3. Csapo R, Hoser C, Gfoller P, et al. Fitness, knee function and competition performance in professional alpine skiers after ACL injury. *J Sci Med Sport* 2019;22 Suppl 1:S39-S43. doi: 10.1016/j.jsams.2018.06.014 [published Online First: 2018/07/08]
4. Ebert JR, Annear PT. ACL Reconstruction Using Autologous Hamstrings Augmented With the Ligament Augmentation and Reconstruction System Provides Good Clinical Scores, High Levels of Satisfaction and Return to Sport, and a Low Retear Rate at 2 Years. *Orthop J Sports Med* 2019;7(10):2325967119879079. doi: 10.1177/2325967119879079 [published Online First: 2019/11/07]

5. Gupta R, Sood M, Malhotra A, et al. Low re-rupture rate with BPTB autograft and semitendinosus gracilis autograft with preserved insertions in ACL reconstruction surgery in sports persons. *Knee Surg Sports Traumatol Arthrosc* 2018;26(8):2381-88. doi: 10.1007/s00167-017-4790-5 [published Online First: 2017/11/16]
6. Jang SH, Kim JG, Ha JK, et al. Functional performance tests as indicators of returning to sports after anterior cruciate ligament reconstruction. *Knee* 2014;21(1):95-101. doi: 10.1016/j.knee.2013.08.017 [published Online First: 2013/10/01]
7. Gobbi A, Francisco R. Factors affecting return to sports after anterior cruciate ligament reconstruction with patellar tendon and hamstring graft: a prospective clinical investigation. *Knee Surg Sports Traumatol Arthrosc* 2006;14(10):1021-8. doi: 10.1007/s00167-006-0050-9 [published Online First: 2006/02/24]

Author Names Searched:

Amelia J.H. Arundale
Francesco Della Villa

Appendix B.2 MINORS Scores for Included Studies

Supplemental Table 9: MINORS Scores

Study	MINORS Score	Bias Risk
Csapo *et al*.	12/16	Low
Ebert *et al*.	13/16	Low
King *et al*. (ipsilateral reinjury)	19/24	Low
King *et al*. (contralateral injury)	20/24	Low
Kyristis *et al*.	11/16	High
van Melick *et al*.	10/16	High
Welling *et al*.	14/16	Low

	Csapo 2019	Ebert 2019	King 2021 (Ipsilateral reinjury)	King 2021 (Contralateral reinjury)	Kyritsis 2016	van Melick 2022	Welling 2020
1. A clearly stated aim	2	2	2	2	2	2	2
2. Inclusion of consecutive patients	2	2	2	2	2	2	2
3. Prospective collection of data	0	2	2	2	2	2	2
4. Endpoints appropraite to the aim of the study	2	2	2	2	2	2	2
5. Unbiased assessment of the study endpoint	2	2	0	0	0	0	2
6. Follow-up period appropriate to the aim of the study	2	2	2	2	1	2	2
7. Loss to follow-up less than 5%	2	1	1	2	2	0	2
8. Prospective calculation of the study size	0	0	0	0	0	0	0
Items 9-12 specific to comparative studies:							
9. An adequate control group			2	2			
10. Contemporary groups			2	2			
11. Baseline equivalence of groups			2	2			
12. Adequate statistical analysis			2	2			
Total score:	12/16	13/16	19/24	20/24	11/16	10/16	14/16

Appendix B.3 Individual Study Results by Outcome

Supplemental Table 10: Individual Study Results by Outcome

Table 10a: Summary measures of Return to Participation vs Non-Return to Participation Groups*

Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Participation Group	Non-Return to Participation	*p*	Effect Size**
Landing Error Scoring System:				
Counter Movement Jump, ipsilateral side (mean (SD), points)[a]	4.5 (2.6)	5.4 (2.1)	.097	0.37
Counter Movement Jump, contralateral side (mean (SD), points)[a]	**4.2 (2.5)**	**5.5 (2.2)**	**.014**	**0.55**
Hop Tests:				
Single Leg Hop-and-Hold Test:				
Passed on the ipsilateral side, n (%)[a]	**58 (90.6%)**	**21 (70.0%)**	**.015**	**4.14**
Passed on the contralateral side, n (%)[a]	**62 (96.9%)**	**20 (66.7%)**	**< .001**	**15.50**
Single Leg Hop Test:				
Single leg hop ipsilateral side (mean (SD), cm)[a]	**131.8 (22.6)**	**116.6 (25.5)**	**.004**	**0.65**
Single leg hop contralateral side (mean (SD), cm)[a]	**133.2 (21.6)**	**119.7 (25.9)**	**.009**	**0.59**
Single leg hop limb symmetry index (mean (SD), %)[a]	99.2 (6.1)	97.8 (7.8)	.344	0.21

Table 10a (continued): Summary measures of Return to Participation vs Non-Return to Participation Groups*

Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Participation Group	Non-Return to Participation	*p*	Effect Size**
<u>Side Hop Test:</u>				
Side hop ipsilateral side (mean (SD), number)[a]	**40.8 (13.4)**	**34.5 (14.0)**	**.040**	**0.46**
Side hop contralateral side (mean (SD), number)[a]	**42.1 (13.5)**	**35.0 (13.8)**	**.021**	**0.52**
Side hop limb symmetry index (mean (SD), %)[a]	97.6 (13.2)	94.6 (19.5)	.391	0.19
<u>Vertical Jump Test:</u>				
Vertical jump ipsilateral side (mean (SD), cm)[a]	**14.9 (3.6)**	**12.8 (3.3)**	**.008**	**0.60**
Vertical jump contralateral side (mean (SD), cm)[a]	**16.0 (3.3)**	**14.2 (3.1)**	**.013**	**0.56**
Vertical jump limb symmetry index (mean (SD), %)[a]	92.8 (12.6)	90.4 (12.7)	.391	0.19
<u>Quadriceps Isometric Strength Test</u>				
Ipsilateral side (mean (SD), kg)[a]	**59.5 (17.5)**	**52.4 (12.0)**	**.049**	**0.44**
Contralateral side (mean (SD), kg)[a]	58.8 (17.3)	52.3 (13.3)	.073	0.40
Limb symmetry index (mean (SD), %)[a]	101.7 (10.0)	100.9 (9.5)	.718	0.08
<u>Hamstring Isometric Strength Test</u>				
Ipsilateral side (mean (SD), kg)[a]	30.5 (5.7)	28.7 (6.3)	.163	0.31
Contralateral side (mean (SD), kg)[a]	32.2 (6.0)	30.4 (5.8)	.177	0.30
Limb symmetry index (mean (SD), %)[a]	95.2 (11.6)	94.7 (14.9)	.857	0.04
<u>Hamstring Eccentric Test (break test)</u>				
Ipsilateral side (mean (SD), kg)[a]	29.1 (5.6)	26.7 (5.6)	.054	0.43

Table 10a (continued): Summary measures of Return to Participation vs Non-Return to Participation Groups*

Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Participation Group	Non-Return to Participation	*p*	Effect Size**
Contralateral side (mean (SD), kg)[a]	**30.7 (5.6)**	**28.3 (4.5)**	**.044**	**0.45**
Limb symmetry index (mean (SD), %)[a]	95.4 (13.3)	95.0 (17.6)	.892	0.03
Hip Abduction Isometric Test:				
Ipsilateral side (mean (SD), kg)[a]	**37.5 (6.7)**	**33.7 (6.7)**	**.011**	**0.57**
Contralateral side (mean (SD), kg)[a]	**36.9 (8.0)**	**32.7 (7.0)**	**.014**	**0.55**
Limb symmetry index (mean (SD), %)[a]	102.7 (10.9)	104.1 (12.2)	.588	-0.12

a = van Melick *et al.* 2021 reference with n = 64 in the Return to Participation group and n = 30 in the Non-Return to Participation group (return to sport at any level); all predictor measures taken at an average of 11.8 months after surgery
*Return to Participation is defined as return to same or lower level of the same sport
**All effect sizes are Hedge's g except in the case of the single-leg hop-and-hold test where odds ratios are reported. (+) indicates the group averages favor the Return to Participation group.

Supplemental Table 10b: Summary measures of Return to Sport vs Non-Return to Sport Groups*

Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Sport Group	Non-Return to Sport	*p*	Effect Size**
Landing Error Scoring System:				
Counter Movement Jump, ipsilateral side (mean (SD), points)[a]	4.3 (2.5)	5.3 (2.4)	.050	0.41
Counter Movement Jump, contralateral side (mean (SD), points)[a]	4.2 (2.5)	5.2 (2.3)	.044	0.42
Jump Landing (mean (SD) points)[b]	**3.1 (1.4)**	**4.4 (2.5)**	**.010**	**0.73**
Hop Tests:				
Single Leg Hop-and-Hold Test:				
Passed on the ipsilateral side, n (mean (SD), %)[a]	**46 (92.0%)**	**33 (75.0%)**	**.032**	**3.83**
Passed on the contralateral side, n (mean (SD), %)[a]	**48 (96.0%)**	**34 (77.3%)**	**.015**	**7.06**
Single Leg Hop Test:				

Supplemental Table 10b (continued): Summary measures of Return to Sport vs Non-Return to Sport Groups*				
Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Sport Group	Non-Return to Sport	*p*	Effect Size**
Single leg hop ipsilateral side (mean (SD), cm)[a]	131.0 (23.6)	122.3 (24.8)	.084	0.36
Single leg hop ipsilateral side (mean (SD), cm)[b]	**163.7 (27.4)**	**142.4 (35.6)**	**.013**	**0.71**
Single leg hop ipsilateral side (mean (SD), cm)[c]	173.0 (31.8)	179.1 (49.1)	.665	-0.15
Single leg hop contralateral side (mean (SD), cm)[a]	132.1 (22.2)	125.2 (25.1)	.163	0.29
Single leg hop contralateral side (mean (SD), cm)[b]	**168.8 (25.6)**	**149.4 (29.5)**	**.011**	**0.73**
Single leg hop contralateral side (mean (SD), cm)[c]	179.4 (24.8)	192.6 (33.6)	.189	-0.46
Single leg hop limb symmetry index (mean (SD), %)[a]	99.4 (6.1)	98.0 (7.2)	.311	0.21
Single leg hop limb symmetry index (mean (SD), %)[b]	97.1 (8.4)	95.0 (13.4)	.445	0.21
Single leg hop limb symmetry index (mean (SD), %)[c]	95.9 (8.2)	91.7 (12.8)	.252	0.40
Triple Hop Test:				
Triple hop ipsilateral side (cm)[b]	**524.8 (84.4)**	**469.3 (91.5)**	**.024**	**0.64**
Triple hop ipsilateral side (cm)[c]	484.5 (104.6)	519.1 (133.8)	.404	-0.29
Triple hop contralateral side (cm)[b]	**538.9 (81.2)**	**487.4 (75.2)**	**.023**	**0.65**
Triple hop contralateral side (cm)[c]	509.1 (82.8)	564.3 (107.4)	.095	-0.59
Triple hop limb symmetry index (%)[b]	97.4 (6.4)	96.1 (9.7)	.509	0.17
Triple hop limb symmetry index (mean (SD), %)[c]	94.5 (9.2)	91.1 (9.6)	.301	0.36
Triple Crossover Hop Test:				
Triple crossover hop ipsilateral side (mean (SD), cm)[c]	434.7 (118.3)	484.1 (137.2)	.264	-0.39
Triple crossover hop contralateral side (mean (SD), cm)[c]	457.4 (100.7)	525.7 (113.6)	.071	-0.64
Triple crossover hop limb symmetry index (mean (SD), %)[c]	93.9 (9.3)	91.2 (12.3)	.471	0.25
6-meter Timed Hop Test:				
6-meter timed hop ipsilateral side (mean (SD), s)[c]	2.3 (0.7)	2.2 (0.7)	.686	-0.14
6-meter timed hop contralateral side (mean (SD), s)[c]	2.1 (0.4)	1.9 (0.4)	.154	-0.50
6-meter timed hop limb symmetry index (mean (SD), %)[c]	95.0 (10.1)	92.3 (10.1)	.437	0.27

Supplemental Table 10b (continued): Summary measures of Return to Sport vs Non-Return to Sport Groups*				
Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Sport Group	Non-Return to Sport	*p*	Effect Size**
Side Hop Test:				
Side hop ipsilateral side (mean (SD), number)[a]	40.6 (13.7)	36.7 (13.9)	.178	0.28
Side hop ipsilateral side (mean (SD), number)[b]	**53.3 (13.1)**	**43.8 (17.1)**	**.021**	**0.66**
Side hop contralateral side (mean (SD), number)[a]	42.2 (13.5)	37.1 (14.0)	.076	0.37
Side hop contralateral side (mean (SD), number)[b]	**54.4 (11.6)**	**46.9 (14.0)**	**.032**	**0.61**
Side hop limb symmetry index (mean (SD), %)[a]	96.8 (12.6)	96.5 (18.3)	.932	0.02
Side hop limb symmetry index (mean (SD), %)[b]	98.0 (14.1)	91.3 (17.1)	.116	0.45
Vertical Jump:				
Vertical jump ipsilateral side (cm)[a]	**14.9 (3.5)**	**13.4 (3.6)**	**.044**	**0.42**
Vertical jump contralateral side (cm)[a]	15.9 (2.9)	14.9 (3.7)	.149	0.30
Vertical jump limb symmetry index (%)[a]	93.6 (11.5)	90.3 (13.6)	.210	0.26
***Quadriceps Isokinetic Strength Tests*:**				
Quadriceps Strength at 60°/s:				
Ipsilateral side (mean (SD), Nm)[b]	223.9 (51.2)	208.0 (42.6)	.246	0.32
Contralateral side (mean (SD), Nm)[b]	239.3 (53.6)	223.4 (45.0)	.272	0.31
Limb symmetry index (mean (SD), %)[b]	93.9 (9.2)	93.5 (9.2)	.869	0.04
Peak torque at 60°/s normalized to body weight (mean (SD), Nm/kg)[b]	3.0 (0.6)	2.8 (0.5)	.124	0.35
Quadriceps Strength at 90°/s:				
Ipsilateral side (mean (SD), Nm)[c]	164.0 (56.3)	181.1 (102.9)	.544	-0.21
Contralateral side (mean (SD), Nm)[c]	183.8 (56.7)	209.5 (96.4)	.329	-0.34
Limb symmetry index (mean (SD), %)[c]	88.8 (13.3)	82.9 (17.6)	.276	0.38

Supplemental Table 10b (continued): Summary measures of Return to Sport vs Non-Return to Sport Groups*				
Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Sport Group	Non-Return to Sport	*p*	Effect Size**
Quadriceps Strength at 180°/s:				
Ipsilateral side (mean (SD), Nm)[b]	158.2 (37.4)	146.7 (34.7)	.266	0.31
Contralateral side (mean (SD), Nm)[b]	167.4 (37.2)	155.2 (34.0)	.230	0.34
Limb symmetry index (mean (SD), %)[b]	94.7 (9.1)	89.6 (24.8)	.186	0.34
Quadriceps Strength at 300°/s:				
Ipsilateral side (mean (SD), Nm)[b]	121.3 (30.2)	112.2 (30.6)	.286	0.30
Contralateral side (mean (SD), Nm)[b]	129.5 (30.5)	120.1 (30.1)	.271	0.31
Limb symmetry index (mean (SD), %)[b]	93.7 (8.7)	93.7 (9.1)	.979	0.00
Quadriceps Isometric Strength Tests:				
Ipsilateral side (mean (SD), kg)[a]	57.4 (16.9)	57.0 (15.7)	.247	0.24
Contralateral side (mean (SD), kg)[a]	56.7 (16.3)	56.8 (16.6)	.961	-0.01
Limb symmetry index (mean (SD), %)[a]	101.6 (10.0)	101.3 (9.8)	.885	0.03
Hamstring Isokinetic Strength Tests:				
Hamstring Strength at 60°/s:				
Ipsilateral side (mean (SD), Nm)[b]	**136.8 (31.9)**	**113.1 (31.4)**	**.009**	**0.75**
Contralateral side (mean (SD), Nm)[b]	137.0 (31.7)	125.1 (36.6)	.203	0.36
Limb symmetry index (mean (SD), %)[b]	**100.1 (9.8)**	**91.3 (8.7)**	**.001**	**0.93**
Hamstring Strength at 90°/s:				
Ipsilateral side (mean (SD), Nm)[c]	100.5 (32.4)	110.5 (53.0)	.507	-0.23
Contralateral side (mean (SD), Nm)[c]	108.4 (37.3)	109.3 (39.7)	.954	-0.02
Limb symmetry index (mean (SD), Nm)[c]	93.9 (15.8)	98.3 (17.2)	.437	-0.27
Hamstring Strength at 180°/s:				
Ipsilateral side (mean (SD), Nm)[b]	**107.9 (25.2)**	**89.9 (24.8)**	**.012**	**0.72**
Contralateral side (mean (SD), Nm)[b]	109.3 (23.8)	98.4 (27.3)	.119	0.44

Supplemental Table 10b (continued): Summary measures of Return to Sport vs Non-Return to Sport Groups*				
Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Sport Group	Non-Return to Sport	*p*	Effect Size**
Limb symmetry index (mean (SD), %)[b]	**98.7 (9.7)**	**91.7 (9.5)**	**.012**	**0.73**
<u>Hamstring Strength at 300°/s</u>:				
Ipsilateral side (mean (SD), Nm)[b]	**91.4 (21.3)**	**76.3 (21.4)**	**.013**	**0.71**
Contralateral side (mean (SD), Nm)[b]	91.4 (20.4)	80.7 (22.2)	.071	0.51
Limb symmetry index (mean (SD), %)[b]	100.1 (9.4)	94.8 (10.4)	.057	0.55
Hamstring to quadriceps ratio at 300°/s (mean (SD)) [b]	0.8 (0.2)	0.7 (0.2)	.179	0.50
<u>Hamstring Isometric Strength Tests</u>:				
Ipsilateral side (mean (SD), kg)[a]	30.1 (5.9)	29.7 (6.1)	.735	0.07
Contralateral side (mean (SD), kg)[a]	32.3 (6.4)	30.9 (5.3)	.247	0.24
Limb symmetry index (mean (SD), %)[a]	93.9 (11.9)	96.3 (13.4)	.359	-0.19
Eccentric (break test) ipsilateral side (mean (SD), kg)[a]	29.0 (5.4)	27.6 (5.9)	.228	0.25
Eccentric (break test) contralateral side (mean (SD), kg)[a]	30.9 (5.9)	28.9 (4.6)	.068	0.38
Eccentric (break test) limb symmetry index (mean (SD), %)[a]	94.9 (13.4)	95.6 (16.2)	.809	-0.05
<u>Hip Abduction Isometric Strength Tests</u>:				
Ipsilateral side (mean (SD), kg)[a]	37.1 (6.4)	35.3 (7.3)	.210	0.26
Contralateral side (mean (SD), kg)[a]	36.6 (8.4)	34.4 (7.2)	.178	0.28
Limb symmetry index (mean (SD), %)[a]	103.0 (11.4)	103.4 (11.3)	.847	-0.04
<u>Knee Range of Motion (ROM)</u>:				
Active flexion ROM, ipsilateral side (mean (SD), deg)[c]	135.7 (7.8)	136.1 (7.9)	.885	-0.05
Active flexion ROM, contralateral side (mean (SD), deg)[c]	142.4 (6.6)	141.5 (6.8)	.707	0.13

Supplemental Table 10b (continued): Summary measures of Return to Sport vs Non-Return to Sport Groups*				
Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Sport Group	Non-Return to Sport	*p*	Effect Size**
Active extension ROM, ipsilateral side (mean (SD), deg)[c]	-0.1 (3.0)	-0.9 (2.0)	.372	0.31
Active extension ROM, contralateral side (mean (SD), deg)[c]	-2.0 (3.1)	-3.5 (3.5)	.189	0.46
Arthrometer knee laxity measurements (KT-1000):				
Laxity at 134 N of force, ipsilateral side (mean (SD), mm)[c]	7.1 (2.1)	7.9 (1.9)	.252	0.40
Difference in laxity between limbs at 134 N of force (mean (SD), mm)[c]	1.0 (0.9)	0.9 (1.9)	.839	0.07
Laxity at maximal manual force, ipsilateral side (mean (SD), mm)[c]	7.6 (1.7)	7.9 (2.1)	.644	0.16
Difference in laxity between limbs at maximal manual force (mean (SD), mm)[c]	1.0 (1.1)	0.8 (1.3)	.623	0.17
Patient-Reported Measures:				
IKDC SKF (mean (SD), points)[b]	82.3 (7.2)	85.6 (8.4)	.387	-0.44
IKDC SKF (mean (SD), points)[c]	90.3 (9.9)	85.2 (12.1)	.180	0.47
Marx Activity Rating Scale (mean (SD), points)[c]	**14.6 (1.9)**	**11.3 (4.1)**	**.004**	**1.08**
Tegner Activity Scale (mean (SD), points)[c]	**8.2 (1.1)**	**7.0 (1.9)**	**.026**	**0.80**
KOOS, Pain subscale (mean (SD), points)[c]	92.0 (10.5)	90.7 (12.4)	.750	0.11
KOOS, Symptoms subscale (mean (SD), points)[c]	89.3 (13.0)	83.4 (14.5)	.219	0.43
KOOS, ADL subscale (mean (SD), points)[c]	95.6 (11.9)	97.2 (6.8)	.644	-0.16
KOOS, Sport/recreation subscale (mean (SD), points)[c]	90.5 (13.5)	86.0 (17.1)	.388	0.30
KOOS, Quality of Life subscale (mean (SD), points)[c]	80.6 (19.2)	73.8 (17.4)	.288	0.37
Modified Cincinnati Knee Rating Score (mean (SD), points)[c]	91.7 (9.5)	88.1 (9.8)	.288	0.37

Supplemental Table 10b (continued): Summary measures of Return to Sport vs Non-Return to Sport Groups*

Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Sport Group	Non-Return to Sport	*p*	Effect Size**
Physical component subscale of the SF-36 (mean (SD), points)[c]	54.4 (4.6)	54.1 (4.6)	.839	0.07
Lysholm score (mean (SD), points)[c]	90.4 (13.1)	87.8 (12.3)	.564	0.20
Knee Outcome Survey (mean (SD), points)[c]	73.0 (10.4)	72.6 (6.7)	.908	0.04
Global Rating of Change Scale (mean (SD), points)[c]	3.1 (1.6)	2.6 (2.4)	.471	0.25

a = van Melick *et al*. 2021 reference with n = 50 in the Return to Sport group and n = 44 in the Non-Return to Sport group; all predictor measures taken at an average of 11.8 months after surgery.
b = Welling *et al*. 2020 reference with n = 46 in the Return to Sport group and n = 18 in the Non-Return to Sport group; all predictor measures taken at an average of 10.1 months after surgery
c = Ebert *et al.* 2019 reference with n = 19 in the Return to Sport group and n = 15 in the Non-Return to Sport group; all predictor measures taken at 1 year after surgery
KOOS = Knee injury and Osteoarthritis Outcome Score

*Return to Sport is defined as return to same level of the same sport
**All effect sizes are Hedge's g except in the case of the single leg hop-and-hold test where odds ratios are reported. (+) indicates the group averages favor the Return to Sport group.

Supplemental Table 10c: Summary measures of Return to Performance vs Non-Return to Performance Groups*

Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Performance Group	Non-Return to Performance Group	*p*	Effect Size**
<u>Physical Performance Measure from the Back in Action test battery</u>:				
Double-leg Stability Test (mean (SD), index)[d]	1.8 (0.3)	1.6 (0.3)	.089	-0.67
Single-leg Stability Test, ipsilateral side (mean (SD), index)[d]	1.9 (0.3)	1.8 (0.3)	.393	-0.33

Supplemental Table 10c: Summary measures of Return to Performance vs Non-Return to Performance Groups*				
Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Performance Group	Non-Return to Performance Group	*p*	Effect Size**
Single-leg Stability Test, contralateral side (mean (SD), index)[d]	1.8 (0.3)	1.7 (0.3)	*0.393*	-0.33
Single-leg Stability Test, deficit (mean (SD), %)[d]	-3.5 (10.6)	-2.8 (11.7)	.876	-0.06
Plyometric Jump Reactive Strength Index (mean (SD), cm/ms)[d]	0.24 (0.06)	0.21 (0.03)	.069	0.72
Double-leg Counter Movement Jump (mean (SD), cm)[d]	45.2 (6.2)	45.9 (10.0)	.835	-0.08
Single-leg Counter Movement Jump, ipsilateral side (mean (SD), cm)[d]	25.3 (6.2)	25.5 (7.6)	.938	-0.03
Single-leg Counter Movement Jump, contralateral side (mean (SD), cm)[d]	28.4 (5.0)	29.0 (6.0)	.775	-0.11
Single-leg Counter Movement Jump, deficit (mean (SD), %)[d]	-11.4 (11.4)	-12.0 (18.4)	.917	0.04
Speedy jump, ipsilateral side (mean (SD), sec)[d]	4.9 (0.6)	5.0 (0.3)	.534	0.24
Speedy jump, contralateral side (mean (SD), sec)[d]	4.7 (0.4)	4.9 (0.4)	.200	0.50
Speedy jump deficit (mean (SD), %)[d]	-4.4 (6.1)	-3.7 (5.8)	.755	-0.12
Quick feet (mean (SD), sec)[d]	7.3 (0.9)	7.2 (0.5)	.697	-0.15
Quadriceps Isokinetic Strength Tests at 60°/s:				
Quadriceps Peak Torque, ipsilateral side (mean (SD), Nm)[d]	159.5 (48.8)	165.7 (61.2)	.775	-0.11
Quadriceps Peak Torque, contralateral side (mean (SD), Nm)[d]	196.4 (37.8)	203.8 (52.2)	.697	-0.15
Quadriceps deficit (mean (SD), %)[d]	-19.2 (17.2)	-20.0 (12.6)	.876	0.06

Supplemental Table 10c (continued): Summary measures of Return to Performance vs Non-Return to Performance Groups*

Clinical/Performance-Based Test or Patient-Reported Measure of Function	Return to Performance Group	Non-Return to Performance Group	*p*	Effect Size**
Hamstring Isokinetic Strength Tests at 60°/s:				
Hamstring Peak Torque, ipsilateral side (mean (SD), Nm)[d]	97.3 (17.7)	106.4 (32.8)	.422	-0.31
Hamstring Peak Torque, contralateral side (mean (SD), Nm)[d]	113.7 (22.0)	114.3 (30.9)	.958	-0.02
Hamstring deficit, (mean (SD), %)[d]	-13.8 (10.1)	-6.2 (14.6)	.145	-0.57
Hamstring to quadriceps ratio, ipsilateral side (mean (SD), %)[d]	63.7 (12.0)	66.5 (11.3)	.534	-0.24
Hamstring to quadriceps ratio, contralateral side (mean (SD), %)[d]	58.1 (6.3)	56.1 (6.6)	.422	0.31
Patient-Reported Measures:				
Tegner Activity Scale administered at 6 months after surgery (mean (SD), points)[d]	7.6 (1.2)	7.8 (0.8)	.586	-0.21
Lysholm score administered at 6 months after surgery (mean (SD), points)[d]	93.2 (6.0)	92.9 (6.3)	.896	0.05
Visual analog scale for pain at 0 months after surgery (mean (SD), points)[d]	0.4 (0.7)	0.3 (0.5)	.640	-0.18
Visual analog scale for pain at 6 months after surgery (mean (SD), points)[d]	0.4 (0.5)	0.8 (1.0)	.237	0.46

d = Csapo *et al.* 2018 reference with n = 10 in the Return to Performance group and n= 21 in the Non-Return to Performance group; all predictor measures taken at 161.5 days (5.4 months) after surgery with exception of Patient-Reported Measures as noted.
*Return to Participation is defined as return to the same or better sport-specific metric.
**All effect sizes are Hedge's g. (+) indicates the group averages favor the Return to Performance group.

Table 10d: Summary of Measures for Reinjury vs No Reinjury Groups

Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Ipsilateral Reinjury Group	Ipsilateral Reinjury Group	*p*	Effect Size**
Quadriceps Isokinetic Strength Tests:				
Quadriceps Strength at 60°/s:				
Peak torque to body weight, ipsilateral side (mean (SD), %)[e]	303 (55)	309 (74)	.65	-0.10
Peak torque to body weight, contralateral side (mean (SD), %)[e]	331 (62)	339 (73)	.55	-0.13
Bilateral difference at 60°/s (mean (SD), %)[e]	-8 (13)	-9 (14)	.88	0.08
Peak force per body mass, ipsilateral side (mean (SD), N/kg)[f]	200 (39)	198 (43)	.724	0.05
Peak force per body mass, limb symmetry index (mean (SD), %)[f]	88.1 (13.1)	89.4 (11.9)	.652	-0.10
Success rate of ≥90% limb symmetry index of peak force per body mass (%)[f]	47	52	.644	
Quadriceps Strength at 180°/s:				
Peak torque to body weight, ipsilateral side (mean (SD), %)[e]	217 (36)	207 (41)	.23	0.27
Peak torque to body weight, contralateral side (mean (SD), %)[e]	238 (35)	235 (38)	.69	0.08
Bilateral difference at 180°/s (mean (SD), %)[e]	-9 (10)	-12 (12)	.21	0.29
Quadriceps Strength at 300°/s:				
Peak torque to body weight, ipsilateral side (mean (SD), %)[e]	177 (32)	167 (30)	.16	0.32
Peak torque to body weight, contralateral side (mean (SD), %)[e]	189 (27)	185 (33)	.36	0.14
Bilateral difference at 300°/s (mean (SD), %)[e]	- 6 (13)	- 9 (12)	.32	0.23
Quadriceps Power:				
Average power at 60°/s, ipsilateral side (mean (SD), W)[e]	149 (32)	146 (37)	.65	0.09
Average power at 60°/s, contralateral side (mean (SD), W)[e]	163 (35)	160 (38)	.67	0.08
Average power at 180°/s, ipsilateral side (mean (SD), W)[e]	277 (57)	264 (65)	.29	0.22
Average power at 180°/s, contralateral side (mean (SD), W)[e]	301 (58)	296 (67)	.68	0.08
Average power at 300°/s, ipsilateral side (mean (SD), W)[e]	280 (61)	259 (51)	.11	0.35
Average power at 300°/s, contralateral side (mean (SD), W)[e]	303 (60)	292 (64)	.40	0.18

Table 10d (continued): Summary of Measures for Reinjury vs No Reinjury Groups

Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Ipsilateral Reinjury Group	Ipsilateral Reinjury Group	*p*	Effect Size**
Hamstring Isokinetic Strength Tests:				
Hamstring Strength at 60°/s:				
Peak torque to body weight, ipsilateral side (mean (SD), %)[e]	**172 (31)**	**159 (33)**	**.05**	**0.41**
Peak torque to body weight, contralateral side (mean (SD), %)[e]	180 (28)	174 (30)	.30	0.21
Bilateral difference at 60°/s (mean (SD), %)[e]	- 4 (13)	-8 (14)	.16	0.30
Hamstring to quadriceps ratio, ipsilateral side (mean (SD), %)[e]	**58 (10)**	**53 (11)**	**.04**	**0.49**
Hamstring to quadriceps ratio, contralateral side (mean (SD), %)[e]	55 (8)	52 (8)	.15	0.38
Peak force per body mass, ipsilateral side (mean (SD), N/kg)[f]	127.1 (28.6)	122.6 (25.1)	.488	0.16
Peak force per body mass, limb symmetry index (mean (SD), %)[f]	96.5 (13.9)	93 (14.4)	.2745	0.25
Success rate of ≥90% limb symmetry index of peak force per body mass (%)[f]	**69**	**45**	**.022**	
Hamstring Strength at 180°/s:				
Peak torque to body weight, ipsilateral side (mean (SD), %)[e]	140 (26)	129 (27)	.07	0.42
Peak torque to body weight, contralateral side (mean (SD), %)[e]	145 (24)	137 (24)	.13	0.33
Bilateral difference at 180°/s (mean (SD), %)[e]	- 3 (13)	- 5 (15)	.54	0.15
Hamstring to quadriceps ratio, ipsilateral side (mean (SD), %)[e]	65 (10)	63 (13)	.51	0.19
Hamstring to quadriceps ratio, contralateral side (mean (SD), %)[e]	61 (9)	58 (7)	.14	0.34
Hamstring Strength at 300°/s:				

Table 10d (continued): Summary of Measures for Reinjury vs No Reinjury Groups

Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Ipsilateral Reinjury Group	Ipsilateral Reinjury Group	*p*	Effect Size**
Peak torque to body weight, ipsilateral side (mean (SD), %)[e]	**128 (24)**	**118 (17)**	**.04**	**0.43**
Peak torque to body weight, contralateral side (mean (SD), %)[e]	134 (23)	126 (23)	.12	0.35
Bilateral difference at 300°/s (mean (SD), %)[e]	- 3 (16)	- 5 (14)	.67	0.13
Hamstring to quadriceps ratio, ipsilateral side (mean (SD), %)[e]	74 (12)	73 (15)	.75	0.08
Hamstring to quadriceps ratio, contralateral side (mean (SD), %)[e]	71 (11)	70 (15)	.50	0.09
<u>Hamstring Power</u>:				
Average power at 60°/s, ipsilateral side (mean (SD), W)[e]	**91 (19)**	**79 (21)**	**.006**	**0.62**
Average power at 60°/s, contralateral side (mean (SD), W)[e]	97 (19)	93 (18)	.31	0.21
Average power at 180°/s, ipsilateral side (mean (SD), W)[e]	**173 (41)**	**154 (32)**	**.03**	**0.48**
Average power at 180°/s, contralateral side (mean (SD), W)[e]	179 (42)	172 (37)	.43	0.17
Average power at 300°/s, ipsilateral side (mean (SD), W)[e]	**171 (47)**	**148 (30)**	**.02**	**0.51**
Average power at 300°/s, contralateral side (mean (SD), W)[e]	173 (43)	172 (48)	.97	0.02
<u>Work Fatigue at 300°/s</u>:				
Ipsilateral Quadriceps (mean (SD), %)[e]	32 (12)	32 (9)	.98	0.00
Contralateral Quadriceps (mean (SD), %)[e]	34 (9)	34 (15)	.79	0.00
Ipsilateral Hamstring (mean (SD), %)[e]	36 (11)	34 (16)	.41	0.17
Contralateral Hamstring (mean (SD), %)[e]	37 (11)	35 (11)	.32	0.18
<u>Physical Performance Measures</u>:				
Average t test time (mean (SD), s)[e]	10 (1)	10 (1)	.92	0.00

Table 10d (continued): Summary of Measures for Reinjury vs No Reinjury Groups

Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Ipsilateral Reinjury Group	Ipsilateral Reinjury Group	*p*	Effect Size**
Single leg countermovement jump height, ipsilateral side (mean (SD), cm)[f]	9.9 (2.6)	9.9 (2.8)	.964	0.00
Single leg countermovement jump height, limb symmetry index (mean (SD), %)[f]	86 (15.8)	85.4 (16.2)	.875	0.04
Success rate of ≥90% limb symmetry index in the single leg countermovement jump height (%)[f]	44	41	.821	
Single leg drop jump, ipsilateral side (mean (SD), cm)[f]	9.2 (2.7)	9.7 (2.8)	.445	-0.19
Single leg drop jump, limb symmetry index (mean (SD), cm)[f]	76.3 (15.5)	80.1 (17.9)	.224	-0.23
Success rate of ≥90% limb symmetry index in the single leg drop jump height (%)[f]	16	25	.287	
<u>Hop Tests</u>:				
Single hop ipsilateral side (mean (SD), cm)[f]	142.2 (23.3)	148.8 (33.8)	.284	-0.28
Single hop limb symmetry index (mean (SD), %)[e]	97 (6)	99 (5)	.16	-0.34
Single hop limb symmetry index (mean (SD), %)[f]	95.7 (13.7)	95.6 (14.6)	.96	0.01
Success rate of ≥90% limb symmetry index in the single leg hop(%)[f]	68	83	.162	
Triple hop limb symmetry index (mean (SD), %)[e]	98 (7)	99 (4)	.52	-0.15
Triple crossover hop limb symmetry index (mean (SD), %)[e]	99 (7)	99 (8)	.90	0.00
<u>Patient-Reported Measures:</u>				
International Knee Documentation Committee Subjective Knee Form (mean (SD), points)[f]	83.3 (9.9)	79.3 (11.2)	.12	0.39
Marx Activity Scale (mean (SD), points)[f]	11.1 (3.5)	11.3 (3.5)	.25	-0.06
Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Contralateral Injury Group	Contralateral Injury Group	*p*	Effect Size**
<u>Isokinetic Strength Tests</u>:				
<u>Quadriceps Strength at 60°/s</u>:				
Peak force per body mass, contralateral side (mean (SD), N/kg)[g]	**231.3 (36.3)**	**216.3 (38.8)**	**.032**	**0.39**
Peak force per body mass, limb symmetry index (mean (SD), %)[g]	84.2 (14.6)	80.9 (14.6)	.235	0.23
Success rate of ≥90% limb symmetry index of peak force per body mass (%)[g]	36	31	.593	

Table 10d (continued): Summary of Measures for Reinjury vs No Reinjury Groups

Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Contralateral Injury Group	Contralateral Injury Group	*p*	Effect Size**
<u>Hamstring Strength at 60°/s</u>:				
Peak force per body mass, contralateral side (mean (SD), N/kg)[g]	135.7 (23.4)	127.3 (24.9)	.063	0.35
Peak force per body mass, limb symmetry index (mean (SD), %)[g]	96.5 (10.6)	96.9 (14.5)	.894	-0.03
Success rate of ≥90% limb symmetry index of peak force per body mass (%)[g]	73	73	.982	
<u>Physical Performance Tests:</u>				
Single leg countermovement jump height, contralateral side (mean (SD), cm)[g]	11.9 (2.4)	12.1 (2.3)	.561	-0.09
Single leg countermovement jump height, limb symmetry index (mean (SD), %)[g]	84.4 (14.6)	85.8 (13.2)	.627	-0.10
Success rate of ≥90% limb symmetry index on the single leg countermovement jump height (%)[g]	38	40	.792	
Single leg drop jump, contralateral side (mean (SD), cm)[g]	12.4 (2.7)	12.1 (3.2)	.564	0.10
Single leg drop jump, limb symmetry index (mean (SD), %)[g]	74.1 (14.8)	78.1 (16.7)	.186	-0.25
Success rate of ≥90% limb symmetry index on the single leg drop jump (%)[g]	18	12	.393	
Hop Tests:				
Single hop contralateral side (mean (SD), cm)[g]	154.9 (19.9)	152.3 (27.0)	.562	0.11
Single hop limb symmetry index (mean (SD), %)[g]	94.2 (12.4)	95.1 (15.5)	.749	-0.06
Success rate of ≥90% limb symmetry index on the single leg hop (%)[g]	66	61	.645	
<u>Patient-Reported Measures:</u>				
International Knee Documentation Committee Subjective Knee Form (mean (SD), points)[f]	82.4 (10.6)	79.1 (12.0)	.17	0.29
Marx Activity Scale (mean (SD), points)[f]	11.2 (3.2)	10.8 (3.5)	.29	0.12

Table 10d (continued): Summary of Measures for Reinjury vs No Reinjury Groups

Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Reinjury Group*	Reinjury Group*	*p*	Effect Size**
Landing Error Scoring System:				
Counter Movement Jump, ipsilateral side (mean (SD), points)[a]	4.8 (2.5)	4.5 (0.7)	.867	-0.12
Counter Movement Jump, contralateral side (mean (SD), points)[a]	4.7 (2.4)	3.5 (2.1)	.485	-0.50
Jump Landing (mean (SD), points)[b]	3.6 (1.8)	2.6 (1.9)	.114	-0.55
Hop Tests:				
Single Leg Hop-and-Hold Test:				
Passed the single leg hop-and-hold test, ipsilateral side, n (%)[a]	78 (84.8%)	1 (50.0%)	.234	5.57
Passed the single leg hop-and-hold test, contralateral side, n (%)[a]	81 (88.0%)	1 (50.0%)	.169	7.36
Single Leg Hop Test:				
Single leg hop ipsilateral side (mean (SD), cm)[b]	158.9 (32.4)	151.3 (24.2)	.487	0.24
Single leg hop ipsilateral side (mean (SD), cm)[a]	126.5 (24.3)	149.0 (31.1)	.200	-0.92
Single leg hop contralateral side (mean (SD), cm)[b]	164.9 (28.0)	154.9 (27.5)	.298	0.36
Single leg hop contralateral side (mean (SD), cm)[a]	128.4 (23.8)	150.5 (7.8)	.195	-0.93
Single leg hop limb symmetry index (mean (SD), %)[b]	96.2 (10.3)	98.1 (8.5)	.581	-0.19
Single leg hop limb symmetry index (mean (SD), %)[a]	98.7 (6.5)	99.0 (15.6)	.944	-0.05
Triple Hop Test:				
Triple hop ipsilateral side (mean (SD), cm)[b]	511.2 (94.2)	498.3 (58.9)	.684	0.14
Triple hop contralateral side (mean (SD), cm)[b]	529.2 (85.9)	498.8 (56.4)	.285	0.37
Triple hop limb symmetry index (mean (SD), %)[b]	96.5 (7.7)	99.9 (4.9)	.185	-0.46
Side Hop Test:				

Table 10d (continued): Summary of Measures for Reinjury vs No Reinjury Groups

Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Reinjury Group*	Reinjury Group*	*p*	Effect Size**
Side hop ipsilateral side (mean (SD), number)[b]	50.7 (15.0)	49.9 (15.0)	.885	0.05
Side hop ipsilateral side (mean (SD), number)[a]	38.7 (13.8)	40.5 (19.1)	.856	-0.13
Side hop contralateral side (mean (SD), number)[b]	52.6 (13.0)	50.6 (11.3)	.642	0.16
Side hop contralateral side (mean (SD), number)[a]	39.8 (13.9)	41.5 (19.1)	.867	-0.12
Side hop limb symmetry index (mean (SD), %)[b]	95.9 (15.3)	97.2 (15.0)	.794	-0.09
Side hop limb symmetry index (mean (SD), %)[a]	96.6 (15.6)	97.0 (1.4)	.967	-0.03
Vertical Jump Test:				
Vertical jump ipsilateral side (mean (SD), cm)[a]	14.2 (3.6)	15.5 (5.0)	.615	-0.36
Vertical jump contralateral side (mean (SD), cm)[a]	15.4 (3.3)	18.5 (5.0)	.195	-0.93
Vertical jump limb symmetry index (mean (SD), %)[a]	92.2 (12.6)	83.0 (4.2)	.308	0.73
***Quadriceps Isokinetic Strength Tests*:**				
Quadriceps Strength at 60°/s:				
Ipsilateral side (mean (SD), Nm)[b]	226.6 (50.2)	224.6 (45.3)	.908	0.04
Contralateral side (mean (SD), Nm)[b]	235.1 (50.9)	233.2 (57.1)	.908	0.04
Limb symmetry index (mean (SD), %)[b]	93.1 (9.1)	97.6 (8.3)	.150	-0.50

Table 10d (continued): Summary of Measures for Reinjury vs No Reinjury Groups

Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Reinjury Group*	Reinjury Group*	*p*	Effect Size**
Quadriceps peak torque at 60°/s normalized to body weight (mean (SD), Nm/kg)[b]	2.9 (0.6)	3.0 (0.4)	.622	-0.17
<u>Quadriceps Strength at 180°/s</u>:				
Ipsilateral side (mean (SD), Nm)[b]	153.4 (36.8)	163.2 (37.2)	.434	-0.27
Contralateral side (mean (SD), Nm)[b]	163.2 (35.9)	168.1 (41.5)	.706	-0.13
Limb symmetry index (mean (SD), %)[b]	94.1 (9.1)	88.6 (28.4)	.248	0.40
<u>Quadriceps Strength at 300°/s</u>:				
Ipsilateral side (mean (SD), Nm)[b]	117.6 (30.3)	124.6 (31.4)	.505	-0.23
Contralateral side (mean (SD), Nm)[b]	126.2 (29.5)	130.9 (36.9)	.663	-0.15
Limb symmetry index (mean (SD), %)[b]	93.2 (8.5)	96.6 (10.1)	.260	-0.39
<u>Quadriceps Isometric Strength Tests:</u>				
Ipsilateral side (mean (SD), kg)[a]	56.9 (16.3)	72.5 (0.7)	.181	-0.96
Contralateral side (mean (SD), kg)[a]	56.4 (16.3)	74.0 (1.4)	.130	-1.09
Limb symmetry index (mean (SD), %)[a]	101.5 (9.9)	98.0 (2.8)	.615	0.36
<u>Hamstring Isokinetic Strength Tests</u>:				
<u>Hamstring Strength at 60°/s</u>:				

Table 10d (continued): Summary of Measures for Reinjury vs No Reinjury Groups

Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Reinjury Group*	Reinjury Group*	*p*	Effect Size**
Ipsilateral side (mean (SD), Nm)[b]	131.9 (33.8)	120.5 (30.0)	.325	0.34
Contralateral side (mean (SD), Nm)[b]	135.7 (33.9)	122.6 (29.1)	.260	0.39
Limb symmetry index (mean (SD), %)[b]	97.5 (10.3)	98.6 (10.1)	.749	-0.11
Hamstring Strength at 180°/s:				
Ipsilateral side (mean (SD), Nm)[b]	104.0 (26.1)	96.6 (27.2)	.417	0.28
Contralateral side (mean (SD), Nm)[b]	107.1 (25.5)	101.3 (23.4)	.505	0.23
Limb symmetry index (mean (SD), %)[b]	97.2 (10.2)	94.4 (9.4)	.417	0.28
Hamstring Strength at 300°/s:				
Ipsilateral side (mean (SD), Nm)[b]	88.4 (22.0)	80.5 (23.4)	.298	0.36
Contralateral side (mean (SD), Nm)[b]	89.3 (21.5)	83.2 (20.0)	.401	0.29
Limb symmetry index (mean (SD), %)[b]	99.0 (9.3)	96.3 (13.1)	.434	0.27
Hamstring to quadriceps ratio at 300°/s (mean (SD))[b]	0.7 (0.2)	0.6 (0.1)	.127	0.53
Isometric Hamstring Strength Tests:				
Ipsilateral side (mean (SD), kg)[a]	29.8 (5.7)	34.5 (17.7)	.271	-0.79
Contralateral side (mean (SD), kg)[a]	**31.5 (5.7)**	**40.5 (12.0)**	**.032**	**-1.55**

Table 10d (continued): Summary of Measures for Reinjury vs No Reinjury Groups

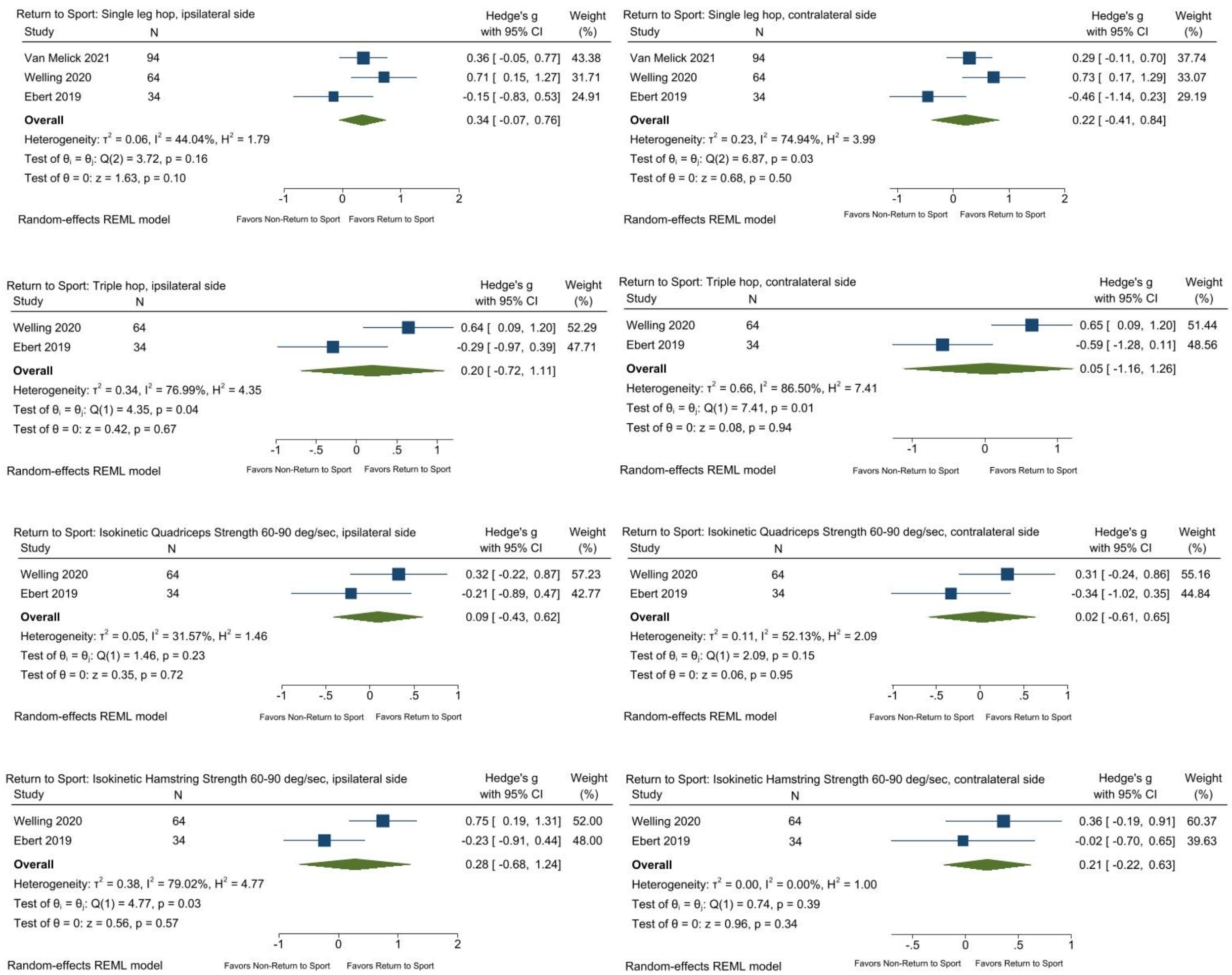
Clinical/Performance-Based Test or Patient-Reported Measure of Function	No Reinjury Group*	Reinjury Group*	*p*	Effect Size**
Limb symmetry index (mean (SD), kg)[a]	95.3 (12.5)	82.5 (19.1)	.156	1.02
Eccentric (break test) ipsilateral side (mean (SD), kg)[a]	28.3 (5.7)	28.5 (6.4)	.955	-0.04
Eccentric (break test) contralateral side (mean (SD), kg)[a]	29.9 (5.4)	32.5 (5.0)	.502	-0.48
Eccentric (break test) limb symmetry index (mean (SD), %)[a]	95.4 (14.8)	87.5 (6.4)	.451	0.54
Isometric Hip Abduction Strength Tests:				
Ipsilateral side (mean (SD), kg)[a]	36.4 (6.8)	32.5 (13.4)	.434	0.56
Contralateral side (mean (SD), kg)[a]	35.5 (7.9)	36.5 (12.0)	.856	-0.13
Limb symmetry index (mean (SD), %)[a]	**103.5 (11.2)**	**87.5 (7.8)**	**.048**	**1.43**
Patient-Reported Measures:				
IKDC SKF (mean (SD), points)[b]	84.1 (7.4)	85.2 (8.4)	.663	-0.15

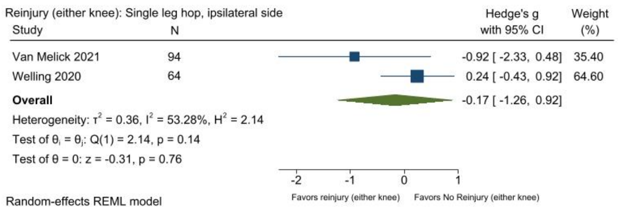
a = van Melick *et al.* 2021 reference with n = 92 in the No Reinjury group and n = 2 in the Reinjury group; all predictor measures taken at an average of 11.8 months after surgery.
b = Welling *et al*. 2020 reference with n = 54 in the No Reinjury group and n = 10 in the Reinjury group; all predictor measures taken at an average of 10.1 months after surgery
e = Kyritsis *et al.* 2016 reference with n = 132 in the Graft Rupture group and n = 26 in the No Graft Rupture group; predictor measures were taken at the end of a criterion-based sport-specific rehabilitation phase
f = King *et al.* 2021 (ipsilateral reinjury) reference with n = 57 in the No Reinjury group and n = 31 in the Reinjury group; all predictor measures taken at an average of 9.3 months (1.2) for the No Reinjury group and 9.1 months (3.1) for Reinjury group.
g = King *et al.* 2021 (contralateral reinjury) reference with n = 60 for the No contralateral injury group and n = 55 for the Contralateral injury group; all predictor measures taken at an average of 9.4 months (1.2) for the No contralateral injury group and 9.0 months (3.1) for Contralateral injury group.

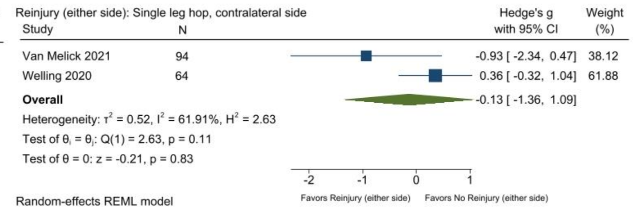
*Reinjury and No Reinjury Groups refer to reinjury to either the ipsilateral or contralateral side in this subsection
**All effect sizes are Hedge's g except in the case of the single-leg hop-and-hold test where odds ratios are reported. (+) indicates the group averages favor the non-reinjured group.

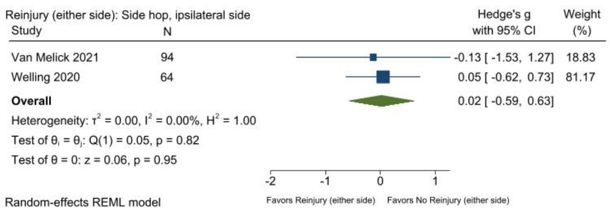
Appendix B.4 Additional Forest Plots

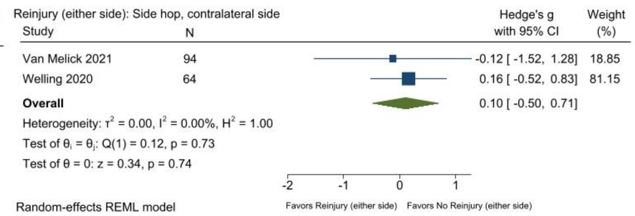
Appendix Figure 1: Additional Forest Plots




Reinjury (either knee): Single leg hop, ipsilateral side
Study
N
Hedge's g with 95% CI
Weight (%)
Van Melick 2021
94
-0.92 [-2.33, 0.48]
35.40
Welling 2020
64
0.24 [-0.43, 0.92]
64.60
Overall
-0.17 [-1.26, 0.92]
Heterogeneity: τ^2 = 0.36, I^2 = 53.28%, H^2 = 2.14
Test of $\theta_i = \theta_j$: Q(1) = 2.14, p = 0.14
Test of θ = 0: z = -0.31, p = 0.76
-2
-1
0
1
Favors reinjury (either knee)
Favors No Reinjury (either knee)
Random-effects REML model


Reinjury (either side): Single leg hop, contralateral side
Study
N
Hedge's g with 95% CI
Weight (%)
Van Melick 2021
94
-0.93 [-2.34, 0.47]
38.12
Welling 2020
64
0.36 [-0.32, 1.04]
61.88
Overall
-0.13 [-1.36, 1.09]
Heterogeneity: τ^2 = 0.52, I^2 = 61.91%, H^2 = 2.63
Test of $\theta_i = \theta_j$: Q(1) = 2.63, p = 0.11
Test of θ = 0: z = -0.21, p = 0.83
-2
-1
0
1
Favors Reinjury (either side)
Favors No Reinjury (either side)
Random-effects REML model


Reinjury (either side): Side hop, ipsilateral side
Study
N
Hedge's g with 95% CI
Weight (%)
Van Melick 2021
94
-0.13 [-1.53, 1.27]
18.83
Welling 2020
64
0.05 [-0.62, 0.73]
81.17
Overall
0.02 [-0.59, 0.63]
Heterogeneity: τ^2 = 0.00, I^2 = 0.00%, H^2 = 1.00
Test of $\theta_i = \theta_j$: Q(1) = 0.05, p = 0.82
Test of θ = 0: z = 0.06, p = 0.95
-2
-1
0
1
Favors Reinjury (either side)
Favors No Reinjury (either side)
Random-effects REML model


Reinjury (either side): Side hop, contralateral side
Study
N
Hedge's g with 95% CI
Weight (%)
Van Melick 2021
94
-0.12 [-1.52, 1.28]
18.85
Welling 2020
64
0.16 [-0.52, 0.83]
81.15
Overall
0.10 [-0.50, 0.71]
Heterogeneity: τ^2 = 0.00, I^2 = 0.00%, H^2 = 1.00
Test of $\theta_i = \theta_j$: Q(1) = 0.12, p = 0.73
Test of θ = 0: z = 0.34, p = 0.74
-2
-1
0
1
Favors Reinjury (either side)
Favors No Reinjury (either side)
Random-effects REML model

Appendix C Return to Sport and Reinjury in Young Athletes Supplementary Material

Appendix C.1 Accuracy of Recall of Sport Participation and Level of Competition up to 6 months after ACLR

The purpose of this study is to assess the level of agreement of responses between baseline and 6 months after ACLR regarding pre-injury sport participation and level of competition. We hypothesized that participants would recall this information with a kappa of at least 0.6, which is classified as a moderate level of agreement.[230] This is important for understanding if accuracy of recall is a concern when we ask the patient clinically about preinjury sport participation and level of competition at later follow-up time points after surgery.

Appendix C.1.1 Methods

Participants included were part of the STABILITY 2 Trial and made up a portion of the total participants in the Return to Sport and Reinjury in Young Athletes after ACLR Study. As part of the STABILITY protocol, participants must fill out a sport participation form at baseline (prior to their ACLR), which included reporting what sport(s) were played prior to injury and the level of competition for each sport. The levels of competition ranged from elite sport playing at the highest level of professional competition 5-7x/week to non-organized sport playing casually less than or equal to 1 day per week.

Cohen’s Kappa was reported for the dichotomous yes/no answer to the questions asking about participation in particular sports. Weighted Kappa was reported for the ordinal questions assessing level of competition within each sport. The participants were only asked about level of sport if they reported yes to participating in the sport first. As there are multiple responses from each participant, the clustered data were analyzed using the clustered bootstrap method to calculate the kappa statistic and its standard error.[231]

Appendix C.1.2 Results

A total of 16 participants were included. The sample was comprised of 10 males (63%), at a median age of 17.1 years old, and a median time from injury to surgery of 1.1 months. Supplemental Table 11 describes the demographic and baseline sport participation data.

Supplemental Table 11: STABILITY 2 Participant Demographics and Baseline Sport Participation

Characteristic	Overall
n	16
Age at time of surgery, median (IQR)	17.1 (16.1-18.7)
Sex, male, n (%)	10 (63%)
Time from injury to surgery in months, median (IQR)	1.1 (0.8-1.5)
Highest level of pre-injury sport played as reported at baseline, n (%)	
Elite Sport	2 (13%)
Varsity Sport	11 (69%)
Competitive Sport	3 (19%)
Recreational Sport	0 (0%)
Non-organized Sport	0 (0%)
Number of pre-injury sports played as reported at baseline, n (%)	
1	6 (38%)
2	7 (44%)
3	1 (6%)
4	2 (13%)

For recall of participation in a sport (dichotomous data), the percent agreement was 97.40% with a Kappa of 0.9051 ($p<0.001$) (Appendix Figure 2). 2 reported varsity track at baseline and not at 6 months; 2 reported water sports at the non-organized level at 6 months but not at baseline; 1 reported competitive softball at 6 months but not at baseline.

	6-months		
Baseline	No	Yes	Total
No	158	3	161
Yes	2	29	31
Total	160	32	192

No = Does not participate

Yes = Does Participate

Appendix Figure 2: Agreement of Sport Participation from Baseline to 6-months

For recall of level of competition in a sport (5 levels of ordinal data), percent agreement was 93.97% with a Kappa of 0.7586 (*p*<0.001, Appendix Figure 3). Appendix Figure 3 highlights the concordant responses in green and the discordant in yellow. All discordant responses were 1 answer choice away from each other. The majority of discordant responses were comprised of a higher rating at baseline compared to 6 months.

Baseline	6-months					Total
	Elite	Varsity	Competitive	Recreational	Non-organized	
Elite	0	3	0	0	0	3
Varsity	0	14	0	0	0	14
Competitive	0	1	4	1	0	6
Recreational	0	0	0	4	2	6
Non-organized	0	0	0	0	0	0
Total	0	18	4	5	2	29

Appendix Figure 3: Agreement of Sport Participation from Baseline to 6-months

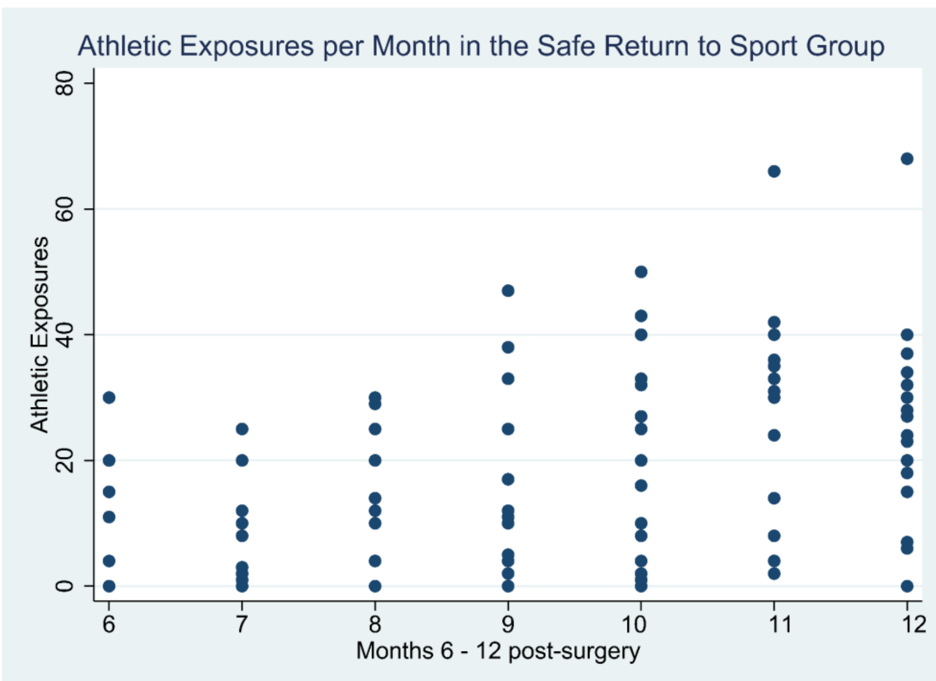
Appendix C.1.3 Discussion and Conclusion

Kappa values of 0.9051 and 0.7586 for sport participation and level of competition, respectively, provide evidence that an athlete will give valid answers when asked about pre-injury sports participation and level of competition up to the 6-month point after ACL reconstruction. Although lower in agreement than sport participation, level of competition recall is still acceptably reliable.

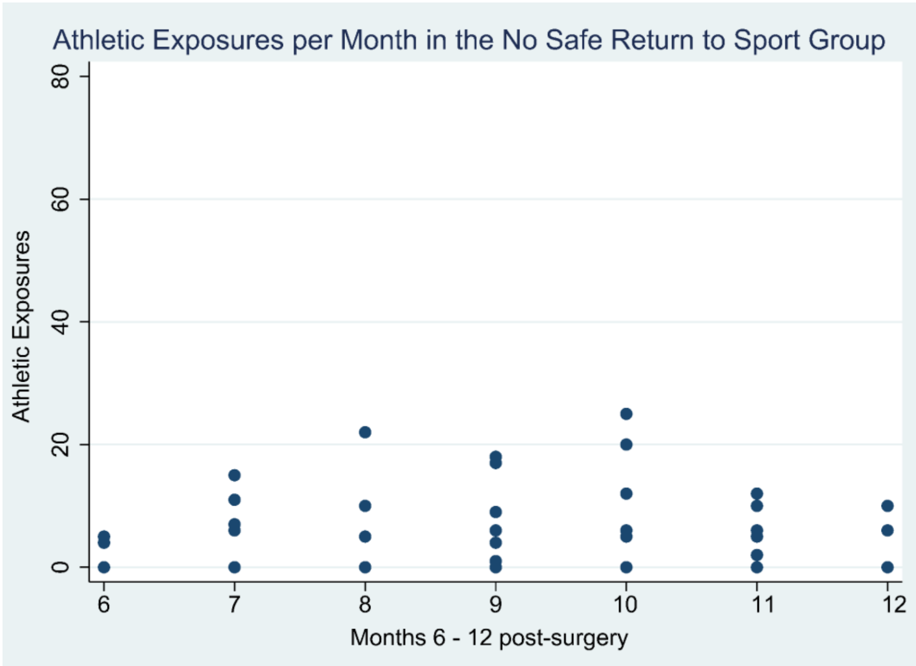
This study was limited by the relatively small number of participants. Additionally, it is possible that these kappa values are over-estimated due to the fact that STABILITY 2 participants get asked if they have returned to sport starting at the 6-month post-operative time point. As the study participants filled out the 6-month measures online, the order of the questionnaires was not controlled for. Having a participant answer questions about their current sport activity and if they have returned to preinjury levels of sport may have had an influence on how they answered questions about their preinjury sport participation.

Overall, these results are reassuring that an athlete can accurately recall their pre-injury sport participation and level of competition at the 6-month post-operative time point. The additional time from baseline to the 6-month follow-up did not substantially alter the athletes' ability to recall this information.

Appendix C.2 Athletic Exposures by Safe Return to Sport Group Membership



Appendix Figure 4 Athletic Exposures per Month in the Safe Return to Sport Group



Appendix Figure 5 Athletic Exposures per Month in the No Safe Return to Sport Group

Appendix C.3 Between-group Differences in Patient-reported Outcome Measures and Performance-based Measures of Physical Function

Supplemental Table 12: Comparison of Safe Return to Sport Groups for Individual Limb Performance in Hop and Strength Testing

Performance-based Measure of Physical Function	Overall Mean (SD)[a]	Safe Return to Sport Group (n=19)	No Safe Return to Sport Group (n=11)	Mean Difference (95% CI)	Correlation with safe return to sport[b], *p* value
Hop Testing: Non-operative Limb[c]					
Single Leg Hop (cm) (median, IQR)	133.0 (102.0 – 174.0)	138.5 (102.0-174.0)	133.0 (98.5-183.0)	p =.75[d] -4.2 (-38.8-30.3)	-0.05, .81
Triple Hop (cm)	447.6 (118.7)	445.3 (122.2)	451.3 (118.4)	-6.0 (-100.9-88.9)	-0.02, .90
Triple Hop Relative to Height	2.6 (0.6)	2.6 (0.6)	2.5 (0.7)	0.01 (-0.5-0.5)	0.01, .96
Triple Crossover Hop (cm) (median, IQR)	375.5 (264.0-498.0)	375.3 (261.0-498.0)	396.0 (264.0-512.0)	p =.79[d] -7.4 (-112.7-97.9)	-0.03, .89
Timed 6-meter Hop (s) (median, IQR)	2.22 (1.89-2.49)	2.21 (1.90-2.49)	2.22 (1.90-3.13)	p =.93[d] -0.12 (-0.72-0.48)	-0.08, .69
Side Hop (n) (median, IQR)	59 (51-67)	61 (52-70)	59 (40-67)	p =.46[d], 6 (-6-18)	0.19, .33
Quadriceps Isokinetic Strength at 90°/sec					

Peak Torque, Non-operative Limb (Nm)	189.2 (74.6)	182.8 (84.4)	200.3 (55.6)	-17.6 (-76.1-40.9)	-0.11, .55
Peak Torque, Operative Limb (Nm)	125.3 (52.2)	121.7 (57.0)	131.6 (44.6)	-9.9 (-51.0-31.1)	-0.09, .63
Average Power, Non-operative Limb (W) (median, IQR)	133.4 (87.1-220.5)	128.2 (85.7-222.5)	136.5 (87.1-178.3)	*p* =.88[d] 6.1 (-54.6-66.7)	0.04, .84
Average Power, Operative Limb (W) (median, IQR)	103.8 (72.1-148.0)	100.8 (67.7-166.4)	107.1 (72.1-139.9)	*p* =.95[d] -0.8 (-42.3-40.6)	-0.01, .97
Hamstring Isokinetic Strength at 90˚/sec					
Peak Torque, Non-operative Limb (Nm)	102.4 (45.3)	97.9 (44.6)	110.4 (47.5)	-12.5 (-48.0-23.0)	-0.13, .48
Peak Torque, Operative Limb (Nm) (median, IQR)	89.1 (56.4-123.7)	78.5 (56.1-127.9)	94.1 (79.0-123.7)	*p* =.75[d] -3.4 (-31.1-24.3)	-0.05, .81
Average Power, Non-operative Limb (W)	84.4 (41.7)	82.7 (44.7)	87.2 (37.9)	-4.5 (-37.4-28.4)	-0.05, .78
Average Power, Operative Limb (W) (median, IQR)	83.7 (50.3-111.4)	67.8 (48.4-133.0)	95.5 (54.7-111.4)	*p* =.91[d] -2.4 (-33.9-29.2)	-0.03, .88

[a]Continuous variables are reported as mean (standard deviation) unless otherwise noted
[b]Point bi-serial correlation
[c]One participant in the Safe Return to Sport Group did not complete non-operative limb hop testing due to apprehension; therefore, n=18 in the Safe Return to Sport group completed hop testing.
[d]Wilcoxon rank-sum (Mann-Whitney U) test performed; mean difference (95% CI (confidence interval)) listed below the p value for the Wilcoxon rank-sum results.

Supplemental Table 13: Comparison between Reinjury Groups for Patient-reported Outcomes and Athletic Exposures

Patient-reported Outcome Measures	Overall Mean (SD)[a]	No Reinjury Group	Reinjury Group	Mean Difference (95% CI)	Correlation with reinjury
ACL-Return to Sport after Injury Scale	64.2 (19.3)	62.9 (18.9)	82.5 (20.7)	-19.6 (-48.1-8.8)	0.25[b]
Knee Self-Efficacy Scale					
$\text{K-SES}_{present}$ (median, IQR)	8.5 (6.6-8.9)	8.3 (6.3-8.9)	9.1 (8.4-9.8)	-1.5 (-4.1-1.2)	0.21[b]

K-SES_{future} (median, IQR)	7.3 (6.0-9.0)	7.3 (6.0-8.8)	8.5 (7.0-10.0)	-1.5 (-4.9-1.9)	0.17[b]
Brief Resiliency Scale	3.8 (0.7)	3.8 (0.7)	3.5 (0.7)	0.3 (-0.8-1.4)	-0.10[b]
High knee-related confidence,[c] n (%)	5 (16.7)	4 (14%)	1 (50%)	36%[d]	0.24[e]
Marx Activity Scale	8.2 (5.5)	7.8 (5.4)	13.5 (3.5)	-5.7 (-13.8-2.3)	0.26[b]
Social Support Questionnaire					
Sources of Social Support	2.6 (1.0)	2.5 (1.0)	3.0 (1.4)	-0.5 (-2.0-1.1)	0.11[b]
Degree of Satisfaction with Support (median, IQR)	5.8 (5.3-6.0)	5.8 (5.3-6.0)	6.0 (6.0-6.0)	-0.49 (-0.8- -0.1)	0.15[b]
IKDC SKF[f]	76.9 (12.9)	76.2 (12.9)	86.2 (9.7)	-10.0 (-29.3-9.2)	0.19[b]
Average Monthly Athletic Exposures from 10-12 months post-surgery (median, IQR)[g]	12.6 (3.9-24.8)	13.6 (4.0-27.1)	10.2 (9.3-11.0)	6.6 (-15.7-28.9)	-0.11[b]

[a]Continuous variables are reported as mean (standard deviation) unless otherwise noted

[b]Point bi-serial correlation

[c]High knee-related confidence was determined by the 3rd question on the Knee Injury and Osteoarthritis Outcome Score (KOOS) quality of life subscale, “How much are you troubled with lack of confidence in your knee?” Those who reported “never” were classified as having high knee-related confidence.

[d]Absolute difference in the percentages in each group is listed as the difference.

[e]Phi coefficient correlation

[f]IKDC SKF = International Knee Documentation Committee Subjective Knee Form

[g]Average monthly exposures were adjusted for re-injury group to reflect the same time period but to exclude the time after reinjury. For the two participants who got reinjured, this meant 0.3 months of exposure data prior to the contralateral ACL injury and 2.6 months of exposure data prior to the ipsilateral medial meniscus tear for the last 3 months of AE data collection.

Supplemental Table 14: Comparison between Reinjury Groups for Performance-based Measures of Physical Function

Performance-based Measures of Physical Function	Overall Mean (SD)[a]	No Reinjury Group	Reinjury Group	Mean Difference (95% CI)	Correlation with reinjury
Hop and Carioca Tests					
Completed hop testing? Yes, n (%)	10 (33)	9 (32)	1 (50)	18%[b]	0.09[c]
Carioca					
Completed carioca testing? Yes, n (%)	16 (53)	12 (54)	1 (50)	4%[b]	0.02[c]
Drop Vertical Jump					
Knee-ankle separation ratio at initial contact (median, IQR)	1.00 (0.87-1.08)	0.99 (0.85-1.08)	1.06 (1.00-1.12)	-0.07 (-0.30-0.16)	0.11[d]
Knee-ankle separation ratio at peak flexion (median, IQR)	1.12 (0.93-1.22)	1.10 (0.91-1.22)	1.19 (1.14-1.23)	-0.10 (-0.38-0.17)	0.14[d]
Plyometric Jump RSI[e] (cm/ms) (median, IQR)					
Double leg	0.05 (0.04-0.09)	0.05 (0.04-0.09)	0.04 (0.02-0.06)	0.02 (-0.03-0.08)	-0.15[d]
Non-operative limb	0.03 (0.02-0.05)	0.03 (0.02-0.05)	0.02 (0.00-0.03)	0.02 (-0.01-0.06)	-0.23[d]
Complete operative limb testing? Yes, n (%)	22 (73)	20 (71)	2 (100)	29%[b]	0.16[c]
Quadriceps Isokinetic Strength at 90°/sec					
Peak Torque LSI[f]	67.7 (17.1)	67.0 (16.9)	77.9 (23.6)	-10.9 (-36.7 - 14.9)	0.16[d]
Average Power LSI (median, IQR)	72.5 (64.7-88.3)	71.1 (63.9-86.1)	142.8 (83.4-202.2)	-59.3 (-133.5-14.8)	0.29[d]
Hamstring Isokinetic Strength at 90°/sec					

Peak Torque LSI	91.9 (18.4)	90.2 (17.3)	116.9 (19.4)	-26.7 (-52.8 - -0.6)	0.36[d]
Average Power LSI (median, IQR)	103.6 (90.9-115.6)	100.3 (88.6-114.8)	154.7 (110.0-199.4)	-47.3 (-128.7-34.0)	0.22[d]
<u>Hamstring/Quadriceps Peak Torque Ratio</u>					
Non-operative Limb (median, IQR)	0.54 (0.50-0.62)	0.53 (0.50-0.61)	0.65 (0.62-0.68)	-0.07 (-0.22-0.08)	0.12[d]
Operative Limb (median, IQR)	0.79 (0.63-0.99)	0.78 (0.63-0.98)	0.90 (0.76-1.04)	-0.11 (-0.46-0.23)	0.12[d]

[a]Continuous variables are reported as mean (standard deviation) unless otherwise noted

[b]Absolute difference in the percentages in each group is listed as the difference.

[c]Phi coefficient correlation

[d]Point bi-serial correlation

[e]RSI = Reactive strength index; System error prevented 2 participants from completing the plyometric jump at all (n=28 for double leg version) and 1 from completing the single-leg plyometric jumps (n = 27 for the nonoperative side). An additional 5 participants had apprehension in completing the operative side plyometric jump, and therefore, the operative side plyometric jump data is presented only as those who completed the test (n = 22). All 5 participants who did not complete the operative side plyometric jump due to apprehension belonged to the non-reinjured group.

[f]Limb Symmetry Index

Supplemental Table 15: Comparison of Reinjury Groups for Individual Limb Performance in Hop and Strength Testing

Performance-based Measure of Physical Function	Overall Mean (SD)[a]	No Reinjury Group (n=28)	Reinjury Group (n=2)	Mean Difference (95% CI)	Correlation with reinjury[b]
Hop Testing: Non-operative Limb[c]					
Single Leg Hop (cm) (median, IQR)	133.0 (102.0 – 174.0)	133.0 (98.5-174.0)	159.0 (108.0-210.0)	-22.9 (-88.5-42.7)	0.13
Triple Hop (cm)	447.6 (118.7)	443.1 (121.2)	507.0 (70.7)	-63.9 (-243.8-116.1)	0.14
Triple Hop Relative to Height	2.6 (0.6)	2.5 (0.6)	2.8 (0.5)	-0.3 (-1.2-0.7)	0.11
Triple Crossover Hop (cm) (median, IQR)	375.5 (264.0-498.0)	375.5 (261.0-498.0)	432.0 (346.5-517.5)	-53.3 (-253.9-147.4)	0.10
Timed 6-meter Hop (median, IQR)	2.22 (1.89-2.49)	2.22 (1.89-2.50)	1.99 (1.66-2.32)	0.38 (-0.78-1.53)	-0.13
Side Hop (n) (median, IQR)	59 (51-67)	59 (51-70)	58 (48-67)	1 (-23-24)	-0.01
Quadriceps Isokinetic Strength at 90˚/sec					
Peak Torque, Non-operative Limb (Nm)	189.2 (74.6)	190.8 (77.0)	166.7 (12.2)	24.1 (-89.3-137.5)	-0.08
Peak Torque, Operative Limb (Nm)	125.3 (52.2)	124.9 (53.2)	131.2 (48.9)	-6.4 (-86.0-73.2)	0.03
Average Power, Non-operative Limb (W) (median, IQR)	133.4 (87.1-220.5)	139.4 (88.4-221.5)	98.5 (87.1-109.9)	53.2 (-62.3-168.6)	-0.17
Average Power, Operative Limb (W) (median, IQR)	103.8 (72.1-148.0)	103.8 (69.9-147.5)	133.9 (91.7-176.1)	-21.1 (-100.8-58.6)	0.10
Hamstring Isokinetic Strength at 90˚/sec					
Peak Torque, Non-operative Limb (Nm)	102.4 (45.3)	103.2 (46.9)	92.0 (4.1)	11.2 (-57.8-80.2)	-0.06
Peak Torque, Operative Limb (Nm) (median, IQR)	89.1 (56.4-123.7)	84.6 (56.3-122.0)	107.9 (91.9-123.9)	-18.3 (-71.4-34.8)	0.13
Average Power, Non-operative Limb (W)	84.4 (41.7)	85.3 (43.1)	71.8 (8.8)	13.5 (-50.0-76.9)	-0.08

Average Power, Operative Limb (W) (median, IQR)	83.7 (50.3-111.4)	75.8 (49.4-110.9)	108.3 (85.8-130.8)	-26.2 (-86.4-34.0)	0.16

[a]Continuous variables are reported as mean (standard deviation) unless otherwise noted
[b]Point bi-serial correlation
[c]One participant in the No Reinjury Group did not complete non-operative limb hop testing due to apprehension; therefore, n=27 in the No Reinjury group completed hop testing.

Appendix D Disclaimers

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Appendix D.1 Publication Record, Disclaimer, and Approval for "Sex, Military Occupation and Rank are Associated with Risk of Anterior Cruciate Ligament Injury in Tactical-Athletes"

This work was presented at the 63rd Annual Meeting of the Society of Military Orthopaedic Surgeons in Olympic Valley, California, USA, December 2021. The preprint of this manuscript is archived on medRxiv at DOI: 10.1101/2021.09.30.21264383. This study was completed by Dr. Aubrey Aguero in partial fulfilment of the academic requirements for the PhD in Rehabilitation Sciences at the University of Pittsburgh.

 The link to the version of record can be accessed here: https://militaryhealth.bmj.com/content/early/2022/02/12/bmjmilitary-2021-002059.

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Ethics approval: The study protocol was approved by the Naval Health Research Center Institutional Review Board in compliance with all applicable Federal regulations governing the protection of human subjects. Research data were derived from an approved Naval Health Research Centre Institutional Review Board protocol, number NHRC.2020.0203-NHSR.

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