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Anterior cruciate ligament injury incidence across sex, sport, and level: a systematic review and meta-analysis

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ANTERIOR CRUCIATE LIGAMENT INJURY INCIDENCE ACROSS SEX, SPORT, AND LEVEL: A SYSTEMATIC REVIEW AND META-ANALYSIS

By

Dana L. Anderson

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Biological Sciences

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This thesis has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Biological Sciences.

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List of Abbreviations

ACL	Anterior Cruciate Ligament
AE	Athlete Exposure
CI	Confidence Interval
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
IR	Injury Rate

Abstract

Well controlled Anterior Cruciate Ligament (ACL) injury prevention neuromuscular training reduces the risk of ACL injury by 50%, but despite the efficacy of these programs, ACL injury rates have not decreased. This lack of decrease in injury incidence may be due in part to limited knowledge on who is most at risk for sustaining an ACL injury, and there is no formal clinical tool available to estimate the personalized or group risk of ACL injury. The purpose of this study was to better understand what groups of athletes are most at risk of sustaining a primary ACL injury, as the first step in mitigating risk and decreasing the substantial public health and financial burden of ACL injuries. To accomplish this goal, we conducted a systematic review and meta-analysis using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and through specific inclusion/exclusion criteria to analyze specific subgroupings of athletes. 7,038 studies were identified in the initial database search and 80 studies were included in the final subgroup meta-analysis. Analyses revealed that female athletes had a greater risk of ACL injury compared to male athletes. However, this project pointed out gaps in the current epidemiological prevalence of ACL injuries and the extra precaution people should take about the overgeneralization of sex and sport types for risk assessment. For example, it is well known that for sex comparable sports, females are at greater risk for ACL injury compared to males – however, the absolute risk level for various female sports is substantially low (e.g., female high school volleyball and female college lacrosse). In addition, female professional sports have overall higher ACL injury rates and prevention programs appear less effective for this group warranting

more rigorous and targeted prevention efforts. Future studies should also utilize rigorous epidemiological approaches to assess injury rates as there are many sports, sex, and levels that do not have sufficient data to determine absolute prevalence or risk level. When more information is discovered, a personalized risk assessment tool can then be developed to then determine the most at-risk populations to allocate resources and prevention efforts to reduce the number of ACL injuries.

1 Introduction

1.1.1 ACL Injuries in Sports

It is estimated that approximately 21 million children, between the ages of 6 and 17, in the United States participate in sports [(50).] Even with this estimation, the number of youth athletes who participate in sports is even higher, because the above number does not include the millions of children who start before the age of 6 [(50).] Participation in such sports is a vital component to fostering long-term health and well-being. However, with these great benefits, there are many risks and consequences involved with competitive sports. Knee injuries are the most common severe [(22)] and season/career ending sport injury [(111),] the majority of which are anterior cruciate ligament (ACL) injuries [(49).] The ACL is a type of cruciate ligament that is found in the front of the distal knee joint and crosses with the posterior cruciate ligament in the back, to form an “X”, when viewing the knee joint. The anterior cruciate ligament prevents the tibia, or shinbone, from sliding out in front of the femur, or thighbone, as well as provides rotational stability to the knee [(4).] ACL injuries can vary from a sprain of the cruciate ligament to a full rupture and is regularly seen through both noncontact and contact (direct) mechanisms. Most commonly, people tend to tear, or rupture the whole ACL. On the other hand, sprains and partial tears are more unusual and may go unrecognized [(121).] About half of all injuries to the anterior cruciate ligament occur in conjunction with damage to other structures in the knee, such as meniscus or other ligaments [(121).]

1.1.2 Impact of ACL Injuries

ACL injuries present a significant impact on our healthcare system. In addition to the financial burden of one ACL injury cost being approximately $38,000 USD [(63),] there are also remarkable personal costs that arise. ACL injured athletes have a higher risk, approximately 4 times, for osteoarthritis [(3), (76), (11), (18),] total knee replacement [(108)] and have impaired knee quality of life in 5-25 years [(32).] There are two treatment options for an ACL injury which include nonsurgical treatments such as a brace or rehabilitation through physical therapy and/or a surgical reconstruction to restore the internal structures of the knee [(121).] Choice of treatment depends on a variety of factors such as severity of the injury, age, and activity level. Usually, people choose reconstruction if they want to return to their sport or are younger in age and want to prevent or prolong the time until arthritis could develop [(121).] When an athlete injures their ACL, they are looking at substantial recovery time of approximately one year. About 45% of injured athletes will not go back to the competitive sport (5), (6), (61) and even if return is possible, performance is likely to decrease upon return [(61), (51).]

1.1.3 Injury Prevention Neuromuscular Training

Well controlled ACL injury prevention neuromuscular training reduces the risk of ACL injury by 50% (from 1 in 66 to 1 in 133) [(106), (107), (102), (73).] Effective injury prevention training programs include landing stabilization exercises such as hopping and holding as well as lower body strengthening exercises such as lunges and hamstring exercises [(122).] The exercises are typically done throughout the season prior to every

practice as a warm-up activity led and supervised by coaches or sports medicine professionals. However, despite knowing the efficacy of prevention programs since 2008, ACL injury rates have not decreased [(1), (2), (33), (45).] A major cause of the continued high incidence is the lack of use of ACL injury prevention training, partly due to limited knowledge on who should receive this training. Certain athlete characteristics have been associated with increased ACL injury risk such as age, sport played, or sex. These various independent factors all influence the risk for ACL injury, but a more comprehensive and usable multivariate model is needed. This model will best characterize risk levels and more likely lead to sustained clinical use and implementation. Nonetheless, this knowledge is still sparse because there is no formal clinical tool available to estimate the personalized risk of ACL injury. A risk assessment program would allow physicians to recommend effective injury prevention programs and advise those around the athlete to make more informed decisions about their health and safety. Simple and accurate risk assessment would increase motivation for prevention initiatives, advance prognostic testing and focus more resources on the most vulnerable individuals and groups of athletes.

1.1.4 Meta-Analysis

In order to determine and compare the rates of ACL injury in female and male athletes across various sport types and levels, the conditions for the data collection must be similar. If the methods of such data collection differ, then it is not possible to compare their injury rates and thus creating a personalized risk assessment tool would be unlikely.

Therefore, statistical analysis approaches like a meta-analysis may prove to be very useful in estimating these injury rates. A meta-analysis is the combining and analyzing of data from multiple studies, at a given time [65]. Utilizing these methods, we can then determine the factors influencing ACL injury likelihood which will help to create a multivariate model that characterizes ACL injury risk.

1.1.5 Current Limitations of Other Studies

While previous meta-analyses and other studies have been conducted on the current epidemiological prevalence of ACL injuries, there were some inherent limitations within them. One such study examined the risk of sustaining ACL injuries in sports, and although information and data was detailed, the study was conflated with intervention protocols [70]. For example, the authors calculated injury rates by including and combining athletes that received an intervention and ones that did not – even though we know prevention programs can reduce risk by about 50%. Athletes in the intervention group should have been excluded or analyzed separately to get a more accurate incidence rate. Prospective studies without an intervention component or even retrospective studies would have been more useful because investigators could use the data to answer questions about risk factors and disease outcomes instead of focusing on if the intervention programs were successful or not. Finally, while this study included a substantial number of articles [58] in their meta-analysis, there was substantial variability in their rate estimates, and they did not try to determine the sources of this variability. Another article reported ACL injury risk within sports based upon the incidence by sex

and sport classification [71]. In this article there was a lack of understandable rate reporting since they studied athlete exposure (AE's) for their analyses. An athlete exposure is defined as one athlete participating in a game or practice, in which he/she is exposed to the possibility of athletic injury [8]. While this is the gold standard for epidemiological rate calculation and for comparing rates, it is hard to understand what the values actually mean from an absolute risk perspective. Upon analyzing and deciphering numerous other articles, we recognized common gaps of knowledge that needed to be addressed. This included things such as significant heterogeneity, which is the increased variability in rates due to diverse groups studied; or focusing on sex differences in many of the studies, which researchers cannot control. We also noticed that it is not known where there is prevalence data missing or where we need to conduct more observational studies to determine injury rates. Lastly there was a lack of translation of data and findings into usable tools and information for the application of future studies and research.

1.1.6 Purpose of the Study

The purpose of this systematic review and meta-analysis was to create a group-based risk assessment tool for athletes by determining the absolute risk level of sustaining an ACL injury across known athlete groups. A secondary aim was to shed light on the sports (sex and levels) where more epidemiological prevalence data are needed.

2 Methods

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRIMSA) guidelines when conducting this systematic review and meta-analysis [(81).]

2.1.1 Eligibility Criteria

A literature search was performed with the electronic databases of PubMed and EBS-Cohost (CINAHL Plus and MEDLINE) on April 20, 2021. A keyword search was conducted with a combination of keywords involving Anterior Cruciate Ligament Injuries AND Epidemiology OR Incidence OR Prevalence AND tear OR rupture. The search was limited to articles published in the English language and all participants were humans. Publication details from all studies identified as eligible were exported to bibliographic software (Endnote X9; Clarivate Analytics, Philadelphia, PA).

2.1.2 Data Inclusion Criteria

Given the large number of studies identified, a single author (D.L.A.) performed the initial screening of articles for inclusion. Articles were first screened by title, next by abstract and then by reading of the study according to the inclusion and exclusion criteria. The following inclusion criteria was applied: (1) Research conducted in athletes playing in organized sports, (2) Total number of ACL injuries (both noncontact and contact in nature) and total number individuals (non-injured) in the population were recorded. Studies were particularly excluded if: (1) secondary ACL injury was detailed, (2) total

population was not identified, (3) mentioned strictly ACL reconstruction, not denoting ACL injuries, (4) multi-sport athletes, and (5) no differentiation between male and female athletes. Any discrepancies were discussed and resolved with a second author (E.J.P). During the literature search, cross-referencing was performed when studies that that met inclusion criteria cited other studies.

2.1.3 Data Extraction and Analysis

Each article was analyzed for the following information: year of publication, type of study, the studies observational time-period, the number of ACL injuries, sample characteristics including type of sport, participation level, mechanism of injury (noncontact vs contact), sex, and total participants. Due to sports being played outside the United States, some levels were hard to establish as uniform. Thus, we grouped semi-professional and collegiate teams together and labeled them as collegiate. The reported person-time unit was not uniform across studies. Thus, to establish a more common metric of comparison we calculated the combined injury rate (IR) for ACL's by taking the absolute value of ACL injuries per year and dividing it by the absolute value of non-injured ACLs. For studies in which the number of ACL injuries could not be established, or total participation was not listed, we emailed authors to gather that data. If they could not provide that data or did not respond, the study was excluded from the meta-analysis. Discrepancies between classifications or values were discussed and resolved between the authors (D.L.A. and E.J.P).

2.1.4 Risk of Bias Assessment

The risk of bias assessment was conducted using the Joanna Briggs Institute Critical Appraisal tool for use in JBI Systematic Reviews [(72).] This tool assessed characteristics such as if the participants were recruited in an appropriate way, if the sample size was adequate, were there valid, and standard methods for all subjects, and if there was appropriate statistical analysis. For each study, the item on the checklist was either answered with a "yes", "no", "unclear" or "not applicable". The full checklist can be seen in *Figure A.3.1 (Appendix A.3).* Out of a checklist of nine items, an overall appraisal was given to the studies on whether to include them in our analysis or not. If criteria were met, and an item was labeled with a "yes" it was scored as 1. If criteria were not met, and an item was labeled with an "unclear" or "no" it was scored as a 0. The maximum score possible was 9. Any discrepancies in scoring were discussed by the two authors (D.L.A. and E.J.P). The studies that received a total score of 8 and above were given a high-quality rating. The studies that received a total score of 7 out of 9 (77%) was given a moderate quality rating. Those that had a total score of 6 out of 9 (66%) was given a moderate/low quality rating. The studies that received a total score of less than or equal to 5 were deemed to be of low quality.

Using the checklist described above, proved to be difficult for some of the studies. As such we modified and added to our criteria for specific questions. For question 3 when it asked if the sample size was adequate, we added a clause that if a study had equal to or greater than 10 ACL injuries, or events, then the sample size was deemed sufficient [(23).]

This was then labeled with a “yes”. If a study particularly examined at intervention techniques, we based our numbers only on the control group, and not each intervention group. Another question we had to pay close attention to, was question 9, which asked if the response rate of the study was adequate, and if not, was the low response rate managed appropriately? Many of the studies did not provide a response rate, and when they did it was hard to normalize what was deemed sufficient. If they did not provide a response rate, they were given the title, “unclear”. When information was given about the rate of response, we decided that no more than 30% dropout (or 70% response rate) was considered adequate and could be labeled with a “yes”.

2.1.5 Risk Categorization

To assign a level of risk to the athlete populations, we ordered the combined meta-analytic injury rate of the individual studies and created three groups (low, moderate, and high). To determine the risk category cut off points, we divided the highest rate by three. Since the rates toward the top of the list included studies with few ACL injuries (e.g., less than 10), thus an imprecise estimate, we chose the rate that included more than 10 injuries as the highest rate to divide by. This corresponded with Male Professional Football for a combined injury rate of 0.030 and then dividing it by three to get a value of 0.010. The lowest combined injury rate was 0 and this was the starting range for the low-risk category. To get the top value of the moderate-risk level 0.010 was added to itself to get a value of 0.020. The ranges for each level of risk are as follows: low risk = 0-0.010, moderate risk = 0.010-0.020, high risk = 0.020>0.030.

2.1.6 Statistical Analysis

The primary outcome of interest for the analysis of our data was the ACL incidence rate per season, by using both univariate subgroup and meta-analysis techniques. Specifically, a random-effects model (using restricted maximum likelihood estimators) was used to calculate the incidence rates per season and statistical parameters such as 95% Confidence Intervals (CI) for the various sport characteristics. For univariate comparisons, only the subgroups defining the sport across each level and sex, with at least two studies ($k \geq 2$) were included in the analysis. All statistical analyses and calculations were performed by use of the packages metafor [114] and meta [10] with the statistical software environment R (RStudio Version, 1.4.1103, the R Foundation for Statistical Computing).

3 Results

The electronic literature search yielded 7038 studies for initial review. 6980 were specifically flagged from the PubMed database, and 58 studies from the Montalvo meta-analysis [(70)] were included in the total number of 7038 studies. Records were removed before screening if the species were not human (n=1168) or not recorded in English (n=280) leaving a total of 5590 studies. We screened titles and abstracts for mentions of the specific keywords and 3630 studies were excluded for lack of relevance to our research. 88 studies could not be found or retrieved, leaving us with a remaining 1872 studies. Next our inclusion and exclusion criteria were applied, which removed 1700 studies, with a new total of 172 studies. These remaining 172 studies were manually cross-referenced, contacted the corresponding authors as needed and excluded 92 studies. The reason for these exclusions were, multi-sport athletes, or not delineating between male and female sexes. At the end of the search, a total of 80 studies were included in our meta-analysis. A flowchart of the literature screening process and review is presented in *Figure 1 (see below).*

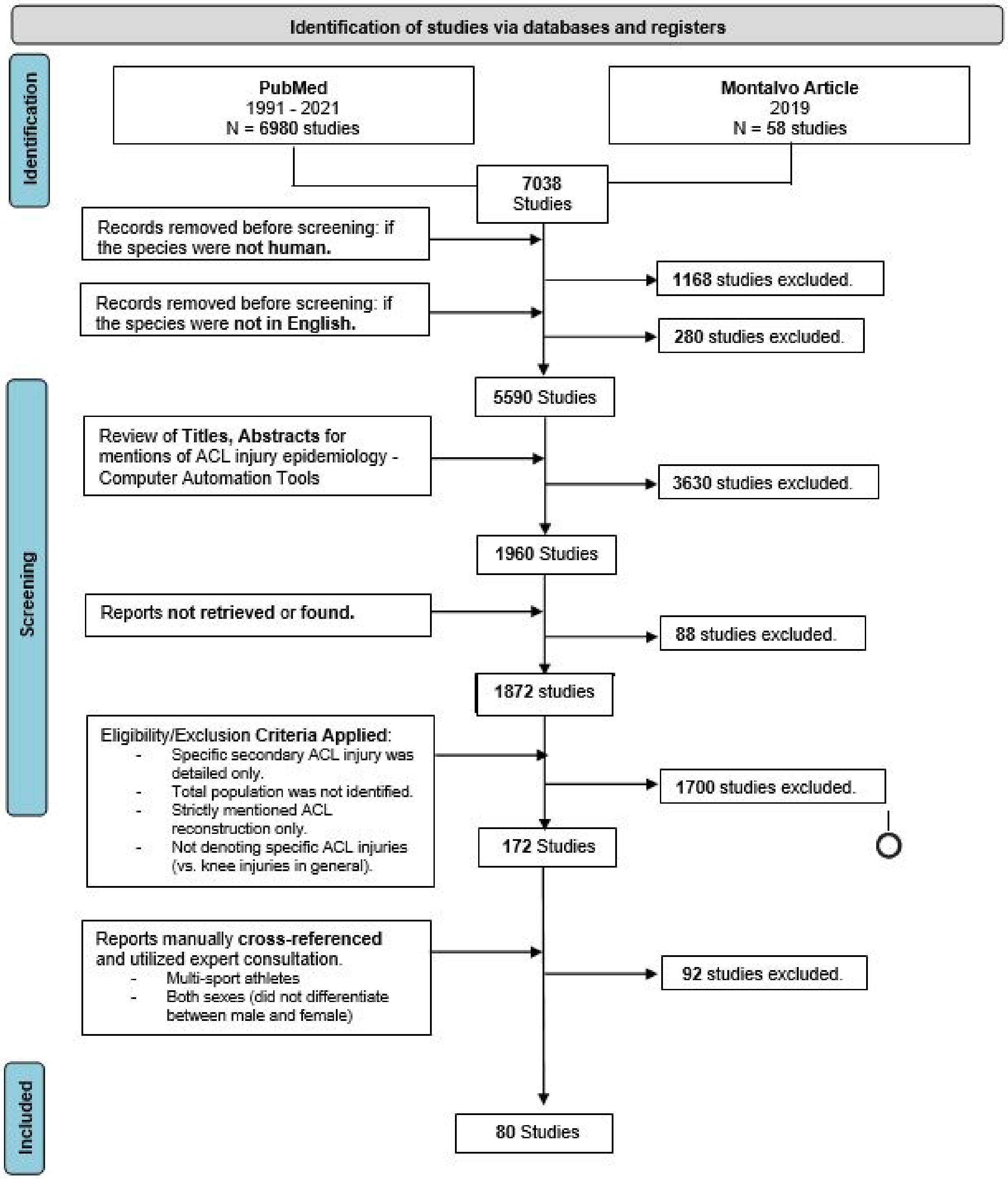

Figure 1: Flowchart summary of the article/literature screening process and review

3.1.1 Risk of Bias Assessment

The results of the risk of bias assessment can be seen in *Figure 2 (or see Appendix A.2*, for a complete list of answers and scores). There were 35 studies out of 80 total studies that received a perfect score of 9 out of 9 points for a proportion of 44%. There were 32 studies out of a total of 80 studies that had a score of 8 out of 9 points for a proportion of 40%. There were 11 studies out of a total of 80 studies that received a score of 7 out of 9 points for a proportion of 14%. Lastly there were 2 studies out of a total of 80 studies that had a score of 6 out of 9 points for a proportion of 2%.

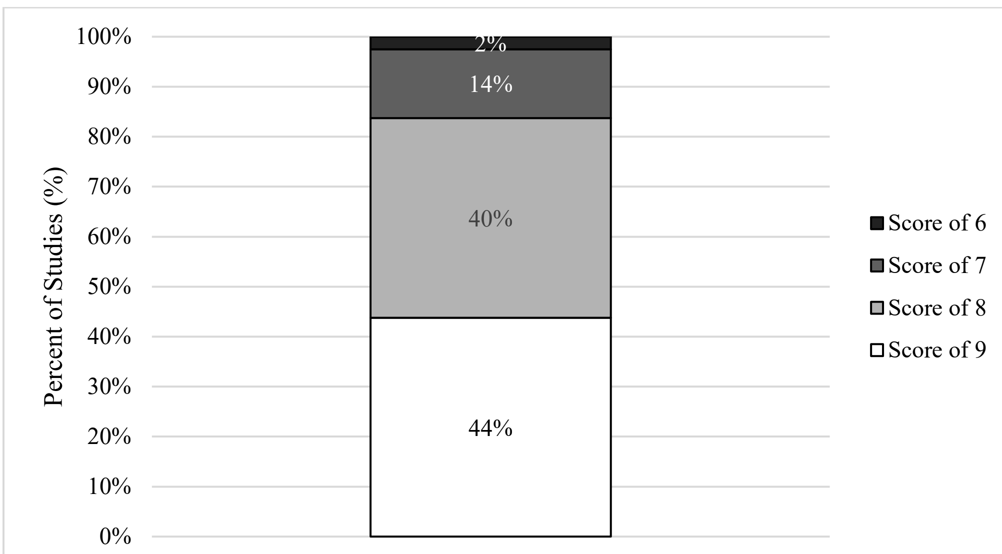

Figure 2: Risk of Bias Assessment Score Proportion[1]

[1] The risk of bias assessment score ranges from a perfect score of 9 to a score of 6 for these specific articles – the lowest possible scores would be 0.

3.1.2 Results by Sport Type/Level/Sex

Figure 3 shows an overview of the data for the combined meta-analytic ACL injury rate in male and female sports, across each level for subgroups that included more than 1 study (e.g., k>1). The studies included in each of the group rate estimates are included in *Table A.1.1 (Appendix A.1)*

Alpine Skiing

There was no data for youth or collegiate alpine skiing teams for either sex identified through our search criteria. There was a total of 2 studies (k=2) found that looked at ACL injury rates in female high school alpine skiers. For this subgroup there was a sum of 5 ACL injuries per season out of 303 athletes and their combined injury rate was 0.018 [0.0058, 0.053]. There was a total of 2 studies (k=2) found that investigated ACL injury rates in male high school alpine skiers. For this subgroup there was a sum of 5 ACL injuries per season out of 382 athletes, and their combined injury rate was 0.014 [0.0057, 0.032]. There was a total of 4 studies (k=4) found that explored ACL injury rates in female professional alpine skiers. For this subgroup there was a sum of 10 ACL injuries per season out of 1,116 athletes and a combined injury rate of 0.010 [0.0047, 0.023]. There was a total of 4 studies (k=4) found for male professional alpine skiers. From this subgroup there was a sum of 10 ACL injuries per season out of 1,522 athletes, for a combined injury rate of 0.0071 [0.0038, 0.013].

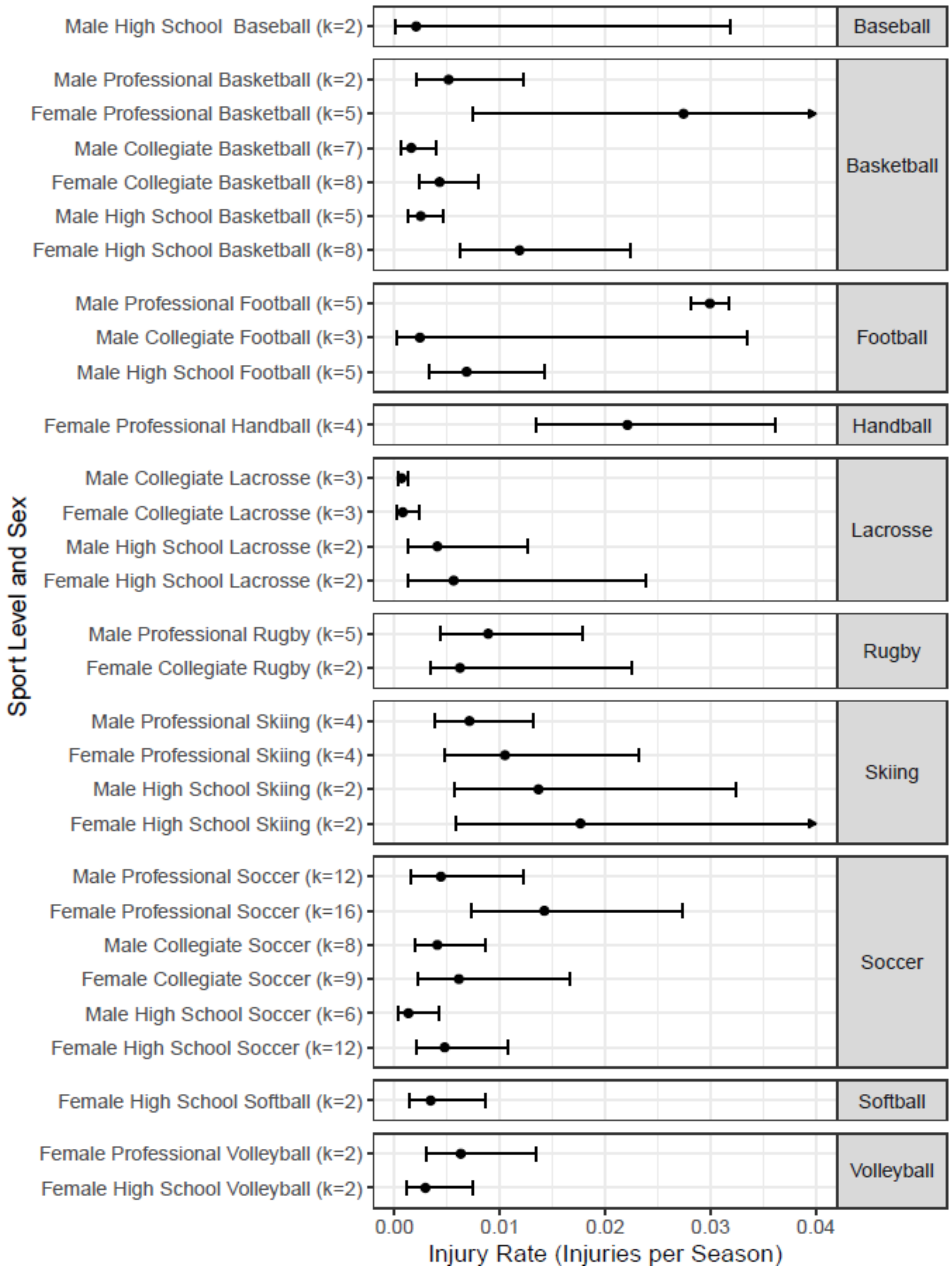

Figure 3: Forest plot for the combined injury rate of anterior cruciate ligament injury in male and female sports, across each level.[2]

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[2] Error bars represent the 95% confidence intervals (CI's).

Basketball

There was no data for youth basketball teams for either sex identified through our search criteria. There was a total of 8 studies (k=8) found that researched ACL injury rates in female high school basketball players. For this subgroup there was a sum of 66 ACL injuries per season out of 6,936 athletes and their combined injury rate was 0.012 [0.0063, 0.022]. There was a total of 5 studies (k=5) found that inspected ACL injury rates in male high school basketball players. For this subgroup there was a sum of 12 ACL injuries per season out of 5,821 athletes and their combined injury rate was 0.0025 [0.0013, 0.0047]. There was a total of 8 studies (k=8) found that examined ACL injury rates in female collegiate basketball players. For this subgroup there was a sum of 196 ACL injuries per season out of 72,391 athletes and their combined injury rate was 0.0043 [0.0023, 0.0079]. There was a total of 7 studies (k=7) found that researched ACL injury rates in male collegiate basketball players. For this subgroup there was a sum of 58 ACL injuries per season out of 70,087 athletes and their combined injury rate was 0.0016 [0.00064, 0.0040]. There was a total of 5 studies (k=5) found that observed ACL injury rates in female professional basketball players. For this subgroup there was a sum of 21 ACL injuries per season out of 1,066 athletes and their combined injury rate was 0.027 [0.0075, 0.096]. There was a total of 2 studies (k=2) found that studied ACL injury rates in male professional basketball players. For this subgroup there was a sum of 5 ACL injuries per season out of 1,002 and their combined injury rate was 0.0051 [0.0021, 0.012].

Floorball

There was no data for youth or collegiate floorball teams for either sex identified through our search criteria. There was also no information found for male professional floorball teams. There was 1 study found (k=1) that surveyed ACL injury rates in female high school floorball players. For this subgroup there was a sum of 3 ACL injuries per season out of 72 athletes, for an injury rate of 0.042 [0.014, 0.12]. There was 1 study (k=1) found that inspected ACL injury rates in female professional floorball players. For this subgroup there was a sum of = 3 ACL injuries per season out of 198 athletes for an injury rate of 0.015 [0.0049, 0.050].

Football

There was no data identified for female football teams at any level through our search criteria. There was also no information found for youth for either sex. There was a total of 5 studies (k=5) found that examined ACL injury rates in male high school football players. For this subgroup there was a sum of 113 ACL injuries per season out of 14,465 athletes and their combined injury rate was 0.0068 [0.0033, 0.014]. There was a total of 3 studies (k=3) found that researched ACL injury rates in male collegiate football players. For this subgroup there was a sum of 82 ACL injuries per season out of 314,2017 athletes and their combined injury rate was 0.0024 [0.00017, 0.033]. There was a 1 study (k=1) found that explored ACL injury rates in male professional football players. This study was a systematic review/data validation study and as such contained 5 individual studies in it that we drew data from. For this subgroup there was an average of 57 ACL

injuries per season out of 1895 athletes and their combined injury rate was 0.030 [0.025, 0.036].

Handball

There was no data for high school or collegiate teams across male handball identified through our search criteria. There was also no information found for youth handball teams for either sex. There was 1 study (k=1) found that examined ACL injury rates in female high school handball players. For this subgroup there was a sum of 4 ACL injuries per season out of 100 athletes, for an injury rate of 0.04 [0.015, 0.10]. There was 1 study (k=1) found that studied ACL injury rates in female collegiate handball players. For this subgroup there was a sum of 5 ACL injuries per season our of 137 athletes, for an injury rate of 0.0365 [0.015, 0.085]. There were 4 studies (k=4) found that surveyed ACL injury rates in female professional handball players. For this subgroup there was a sum of 43 ACL injuries out of 1,786 athletes and their combined injury rate was 0.022 [0.013, 0.036]. There was 1 study (k=1) found that inspected ACL injury rates in male professional handball players. For this subgroup there was a sum of 4 ACL injuries per season out of 182 athletes, for an injury rate of 0.022 [0.0083, 0.057].

Ice Hockey

There was no data for youth or high school ice hockey teams for either sex, identified through our search criteria. There was also no information found for female professional ice hockey players. There was 1 study (k=1) that looked at ACL injury rates

in female collegiate ice hockey players. For this subgroup there was 1 ACL injury per season out 1,019 athletes, for an injury rate of 0.00098 [0.00014, 0.0069]. Another study (k=1) examined ACL injury rates in male collegiate ice hockey players. For this subgroup there was a sum of 3 ACL injuries per season out of 2,117 athletes for an injury rate of 0.0014 [0.00046, 0.0044]. Finally, another manuscript reported (k=1) reported ACL injury rates in male professional ice hockey players. For this subgroup there was a sum of 7 ACL injuries per season out of 2,081 athletes, for an injury rate of 0.0034 [0.0016, 0.0070].

Lacrosse

There was no data for youth or professional lacrosse teams for either sex, identified through our search criteria. There was a total of 2 studies (k=2) found that inspected ACL injury rates in female high school lacrosse players. For this subgroup there was a sum of 8 ACL injuries per season out of 1,408 athletes for and their combined injury rate was 0.0056 [0.0013, 0.024]. There was a total of 2 studies (k=2) found that researched ACL injury rates in male high school lacrosse players. For this subgroup there was a sum of 6 ACL injuries per season out of 1,594 athletes and their combined injury rate was 0.0041 [0.0013, 0.013]. There was a total of 3 studies (k=3) found that reported ACL injury rates in female collegiate lacrosse players. For this subgroup there was a sum of 14 ACL injuries per season out of 29,158 athletes and their combined injury rate was 0.00078 [0.00026, 0.0023]. There was a total of 3 studies (k=3) found that studied ACL injury rates in male collegiate lacrosse players. For this subgroup there was a sum of 15

ACL injuries per season out of 26,049 athletes and their combined injury rate was 0.00066 [0.00035, 0.0013].

Soccer

There was 1 study (k=1) found that looked at ACL injury rates in male recreational soccer. For this subgroup there was a sum of 16 ACL injuries per season out of 1,022 athletes, for an injury rate of 0.016 [0.009, 0.025]. There was a total of 12 studies (k=12) found that explored ACL injuries in female high school soccer. For this subgroup there was a sum of 149 ACL injuries per season out of 156,502 athletes and their combined injury rate was 0.0048 [0.0021, 0.011]. There was a total of 6 studies (k=6) found that looked at ACL injury rates in male high school soccer. For this subgroup there was a sum of 299 ACL injuries per season out of 717,360 athletes and their combined injury rate was 0.0013 [0.00041, 0.0042]. There was a total of 9 studies (k=9) found that examined ACL injuries in female collegiate soccer. For this subgroup there was a sum of 169 ACL injuries per season out of 96,400 athletes and their combined injury rate was 0.0061 [0.0022, 0.017]. There was a total of 8 studies (k=8) found that researched ACL injury rates in male collegiate soccer. For this subgroup there was a sum of 117 ACL injuries per season out of 111,818 athletes and their combined injury rate was 0.0041 [0.0019, 0.0086]. There was a total of 16 studies (k=16) found that investigated ACL injury rates in female professional soccer. For this subgroup there was a sum of 168 ACL injuries per season out of 42,730 athletes and their combined injury rate was 0.0014 [0.0073, 0.027]. There was a total of 12 studies (k=12) found that

reviewed ACL injury rates in male professional soccer. For this subgroup there was a sum of 433 ACL injuries per season out of 328,609 athletes and their combined injury rate was 0.0044 [0.0016, 0.012].

Softball and Baseball

There was no data for youth or professional softball and baseball teams for either sex, identified through our search criteria. There were 2 studies (k=2) found that reported ACL injury rates in female high school softball players. For this subgroup there was 4 ACL injuries per season out of 3,556 athletes and their combined injury rate was 0.0034 [0.0014, 0.0086]. There were 2 studies (k=2) found that examined ACL injury rates in male high school baseball players. For this subgroup there was 2 ACL injuries per season out of 4,398 athletes and their combined injury rate was 0.0021 [0.00013, 0.032]. There was 1 study (k=1) found that explored ACL injury rates in female collegiate softball players. For this subgroup there was 2 ACL injuries per season out of 2,598 athletes, for an injury rate of 0.020 [0.0049, 0.075].

Rugby

There was no data for female high school rugby teams or female professional rugby teams identified through our search criteria. There was also no information found for youth rugby teams for either sex. There was 1 study (k=1) found that looked at ACL injury rates in male high school rugby players. For this subgroup there was 1 ACL injury per season out of 289 athletes, for an injury rate of 0.0035 [0.00049, 0.024]. There were 2

studies (k=2) found that studied ACL injury rates in female collegiate rugby players. For this subgroup there was a sum of 7 ACL injuries per season out of 923 athletes and their combined injury rate was 0.00621 [0.0034, 0.023]. There was 1 study *(k=1)* that inspected ACL injury rates in male collegiate rugby players. For this subgroup there was 1 ACL injury per season out of 119 athletes, for an injury rate of 0.0084 [0.0012, 0.057]. There was a total of 5 studies (k=5) found that researched ACL injury rates in male professional rugby players. For this subgroup there was a sum of 12 ACL injuries per season out of 1,736 athletes and their combined injury rate was 0.0089 [0.0044, 0.018].

Volleyball

There was no data identified for male volleyball teams at any level through our search criteria. There was also no information found for youth volleyball teams for either sex. There was a total of 2 studies (k=2) found that examined ACL injury rates in female high school volleyball players. For this subgroup there was a sum of 4 ACL injuries per season out of 1,577 athletes and their combined injury rate was 0.0029 [0.0012, 0.0074]. There was a total of 2 studies (k=2) found that reported ACL injury rates in female professional volleyball players. For this subgroup there was a sum of 10 ACL injuries per season out of 1,764 athletes and their combined injury rate was 0.0063 [0.0030, 0.013].

Other Sports

The sports that only had one study (k=1) can been seen in *Table A.1.1 (Appendix A.1).* These included High School Handball, Collegiate Handball, Professional Netball,

Collegiate Ice Hockey, Professional Ice Hockey, Youth Soccer, Recreational Soccer, Collegiate Softball and Baseball, High School Rugby, and High School Wrestling.

There were several studies that included various levels of sports, delineated by sex that had 0 events or ACL injuries. They were excluded in our individual meta-analysis divided by subgroup because they are not a reliable estimate but can still be seen in *Table A.1.1 (A.1. Appendix).* These excluded subgroups are as follows: Professional Female Ballet, Professional Male Ballet, Male Professional Dance, Female Collegiate Field Hockey, Male High School Floorball, Male High School Floorball, Female Collegiate, Gymnastics, Male Collegiate Gymnastics, Female Collegiate Volleyball.

3.1.3 Risk Categorization

Female High School Floorball, Female High School Handball and Female Collegiate Handball had a high level of risk associated with them; however, these categorizations could be due to imprecise rates. Male Professional Football, Female Professional Basketball, Female Youth Soccer, Female Professional handball, and Male Professional Handball had a high level of risk associated with them. Although these sport types were the highest risk, it is worth mentioning that some of the confidence intervals are wide due to the low number of injuries. Therefore, these point estimates should be viewed with caution. For a list and values of the moderate-risk and low-risk sports, please refer to *Table 1 (see below).*

Level, Sex	Combined Injury Rate	95% Confidence Interval (Lower Bound)	95% Confidence Interval (Upper Bound)	Level of Risk[3]	Total Number of Injuries
Female High School Floorball	**0.042**	0.0087	0.12	High	3
Female High School Handball	**0.040**	0.011	0.099	High	4
Female Collegiate Handball	**0.037**	0.012	0.083	High	5
Male Professional Football	**0.030**	0.028	0.032	High	915
Female Professional Basketball	**0.027**	0.0075	0.0956	High	14
Female Professional Handball	**0.022**	0.013	0.036	High	43
Male Professional Handball	**0.022**	0.0060	0.055	High	4
Female High School Alpine Skiing	**0.018**	0.0058	0.053	Moderate	5
Female Professional Dance	**0.018**	0.0021	0.060	Moderate	2
Male Recreational Soccer	**0.016**	0.0090	0.025	Moderate	16
Female Professional Floorball	**0.015**	0.0031	0.044	Moderate	3

[3] Low risk combined injury rate range = 0-0.010. Moderate risk combined injury rate range = 0.010-0.020. High risk combined injury rate range = 0.020>0.030.

Female Professional Soccer	**0.014**	0.0073	0.027	Moderate	168
Male High School Alpine Skiing	**0.014**	0.0057	0.032	Moderate	5
Female High School Basketball	**0.012**	0.0063	0.022	Moderate	66
Female Professional Alpine Skiing	**0.010**	0.0047	0.023	Moderate	10
Male Professional Rugby	**0.0089**	0.0044	0.018	Low	12
Male Collegiate Rugby	**0.0084**	0.00020	0.046	Low	1
Male Professional Alpine Skiing	**0.0071**	0.0038	0.013	Low	10
Male High School Football	**0.0068**	0.0033	0.014	Low	113
Female Professional Volleyball	**0.00629**	0.0030	0.013	Low	10
Female Collegiate Rugby	**0.00884**	0.0034	0.023	Low	7
Female Collegiate Soccer	**0.00611**	0.0022	0.017	Low	169
Female High School Lacrosse	**0.00561**	0.0013	0.024	Low	8
Male Professional Basketball	**0.00513**	0.0021	0.012	Low	5

Female High School Soccer	**0.00476**	0.0021	0.011	Low	149
Male Professional Soccer	**0.0044**	0.0016	0.012	Low	433
Female Collegiate Basketball	**0.00428**	0.0023	0.0079	Low	196
Male High School Lacrosse	**0.00406**	0.0013	0.013	Low	6
Male Collegiate Soccer	**0.00406**	0.0019	0.0086	Low	117
Male High School Rugby	**0.00346**	0.00010	0.019	Low	1
Male Professional Ice Hockey	**0.00336**	0.0014	0.0069	Low	7
Female High School Volleyball	**0.00293**	0.0012	0.0074	Low	4
Male High School Basketball	**0.0025**	0.0013	0.0047	Low	12
Male Collegiate Football	**0.0024**	0.00017	0.033	Low	82
Female High School Field Hockey	**0.0023**	0.000058	0.013	Low	1
Male Collegiate Basketball	**0.0016**	0.00064	0.0040	Low	58
Female Professional Netball	**0.0014**	0.00044	0.092	Low	1
Male High School Wrestling	**0.0014**	0.00046	0.0033	Low	5

Male Collegiate Ice Hockey	**0.0014**	0.00046	0.0044	Low	3
Male High School Soccer	**0.0013**	0.00041	0.0042	Low	299
Female Collegiate Ice Hockey	**0.00098**	0.00014	0.0069	Low	1
Female Collegiate Lacrosse	**0.00078**	0.00026	0.0023	Low	14
Male Collegiate Lacrosse	**0.00066**	0.00035	0.0013	Low	15

Table 1: Combined injury rate of anterior cruciate ligament injuries and their associated level of risk

4 Discussion

The purpose of our study was to characterize ACL injury risk across various sports/sex/and levels, as the first step towards creating a risk assessment tool. Throughout the systematic review and meta-analysis, there were many obstacles and gaps within the data of this subject.

It is first worth noting that most of the studies we looked at were of high or moderate quality (84%) while only (16%) were of lower quality. Therefore, the majority of the articles were of low bias and can therefore be considered robust indicators for prevalence estimation.

As seen in *Table 1* the highest risk sports were Female High School Floorball (incidence rate =0.042 [0.0087, 0.12]), Female High School Handball (incidence rate =0.04 [0.011, 0.099]), Female Collegiate Handball (incidence rate = 0.037 [0.012, 0.083]), Male Professional Football (incidence rate = 0.030 [0.028, 0.032]), Female Professional Basketball (incidence rate =0.027 [0.0075, 0.096]), Female Youth Soccer (incidence rate = 0.022 [0.018, 0.028]), Female Professional Handball (incidence rate = 0.022 [0.013, 0.036]), and Male Professional Handball (incidence rate = 0.022 [0.0060, 0.055]). Out of the eight highest risk sports, 6 of them occurred in the female population. It is worth noting that only 4 of these sports had more than 10 ACL injuries, so the estimates are likely to be imprecise compared to previous literature that found girls are 3 times more likely to injure their ACL compared to boys [(37), (103), (85).] Also in these eight subgroupings, 4 of them occurred in the sport of handball.

As mentioned in the methods section of this paper, there were various studies that included sports with 0 ACL injuries. Due to this, we could not use them in our analysis because it was not a reliable estimate. Therefore, more data is needed due to insufficient number of studies and low sample size of the event (i.e., ACL injuries). These studies included the sports of ballet, dance, field hockey, floorball, gymnastics, and volleyball. More research and future studies need to account and look at these subjects to get a more accurate estimation of risk in these sport populations. Common sports were identified through these studies such as basketball or soccer. These more popular sports usually gather information from a surveillance database. However, when looking at *Figure 2* there is not a lot of data for some other sports like Baseball/Softball, Handball or Rugby. Even when conducting the literature search, there were no studies found that looked at various other sports such as tennis or snowboarding. Thus, future studies should focus on including more data for these underrepresented sports, in addition to collecting more surveillance data for these less common subgroups.

In previous literature it is seen that neuromuscular training is most effective at a younger age (14-18), [(73), (93)] and in our study the injury rates were higher for the professional athletes. This is particularly interesting because professional sports have more access to resources and training programs compared to youth or high school level sports. Future research may investigate developing more effective prevention programs for professional athletes to decrease injury rates.

To determine if an article had a sufficient sample size population, we went off the rule of greater than or equal to ten ACL injuries [(23).] There were fifty-three combined categories of sex, sport type and level. Out of these fifty-three subgroups, twenty-four of the subgroups had a sufficient sample size, while twenty-nine had an insufficient sample size. This shows that over half (54%) had less than 10 ACL injuries per subgroup, which again denotes the need for more studies to be conducted.

Although it might be easy to assume and point out that females are more at risk for ACL injury within sports, it cannot be proposed as a blanket statement. This research brings to light a very important fact. Risk is highly dependent on a multitude of things, in particular the type of sport that is played. People should be cautious when grouping or overgeneralization of sex specific injury risk because the type of sport and level also needs to be taken into consideration.

The beginning aim of this project was to create a personalized risk assessment tool for athletes to use to determine their risk of sustaining an ACL injury. However, as research was being conducted it was very apparent that much more research needs to be done within specific subgroups of the athlete population before a tool can be created. Without enough data and information, the injury rates are not reliable.

4.1.1 Limitations

Due to the nature of such a large meta-analysis, with about 80 studies included, there are obvious weaknesses and limitations to this research. First, due to a wide range of inclusion and exclusion criteria there were numerous articles to assess. Some were not

accessible, and others found duplicates. As such, there is always a possibility of not capturing all necessary articles within our search criteria as well as data that is unpublished. Also, not all articles reported the rate of ACL injuries in the same format.

Calculations and other assumptions had to be made which could lead to bias. Many articles were reviewed to find specific inclusion and exclusion criteria, namely the total participants. Not all studies reported this information and thus we had to calculate total participants based upon the average roster size for a specific subgroup of a sport. As this number is not concrete, there can be some variation and bias.

4.1.2 Future Goals

Based upon our research and meta-analysis of numerous articles, a risk assessment tool would prove very useful. We were not able to develop the risk calculator itself, as it would need more data, testing, and validation. However, using the findings of this paper could support general risk assessment to increase motivation for prevention initiatives as well as filling gaps in prevalence data reporting.

4.1.3 Conclusions

There was substantial variability in injury rates within and across sports. In general, the highest injury rates occurred in professional sports, warranting the need for more prevention training initiatives. In a majority of the rates female athletes had a greater risk of ACL injury compared to male athletes. However, due to the gaps in data, this cannot be assumed or made to be true for every sport or level. Researchers and

practitioners need to be cautious about overgeneralization of sex and sport differences in ACL injury risk. Future studies should aim at more complete coverage of sports at all levels of play, and sex to have more data as means of comparison. When more information is discovered, a personalized risk assessment tool can be developed to then determine the most at-risk population to allocate resources and prevention training to reduce the number of ACL injuries.

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A Appendix

A.1 Table of Data Extracted for all Studies Based on Sport Type, Level and Sex

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Alpine Skiing	High School	Female						
		Westin et. al 2020 (119)	1	143	0.0070	0.00020	0.038	9
		Westin et. al 2018 (120)	4	160	0.025	0.0069	0.063	9
		Combined Rate	**5**	**303**	**0.018**	**0.0058**	**0.053**	
		Male						
		Westin et. al 2020 (119)	2	209	0.0096	0.0012	0.034	9
		Westin et. al 2018 (120)	3	173	0.017	0.0036	0.050	9
		Combined Rate	**5**	**382**	**0.014**	**0.0057**	**0.032**	
	Professional	Female						
		Haida et. al 2016 (42)	2	236	0.0085	0.0010	0.030	7
		Pujol et. al 2007 (86)	2	186	0.011	0.0013	0.038	8
		Raschner et. al 2012 (88)	4	172	0.023	0.0064	0.059	8
		Viola et. al 1999 (115)	2	522	0.0038	0.00050	0.014	9
		Combined Rate	**10**	**1116**	**0.010**	**0.0047**	**0.023**	
Ballet	Professional	Female						
		Liederbach et. al 2008 (58)	**0**	**64**	**0**	**0**	**0.056**	9
		Male						
		Liederbach et. al 2008 (58)	**0**	**53**	**0**	**0**	**0.067**	9
Basketball	High School	Female						
		Beynnon et. al 2014 (12)	2	974	0.0021	0.00020	0.0074	9
		Gomez et. al 1996 (36)	11	879	0.013	0.0063	0.022	9
		Hewett et. al 1999 (46)	3	186	0.016	0.0033	0.046	8
		Joseph et. al 2013 (49)	18	1482	0.012	0.0072	0.019	8
		Messina et. al 1999 (64)	11	879	0.015	0.0063	0.022	9
		Oshima et. al 2018 (78)	5	167	0.030	0.0098	0.069	9
		Stanley et. al 2016 (103)	7	2138	0.0033	0.0016	0.0069	8
		Combined Rate	**66**	**6936**	**0.012**	**0.0063**	**0.022**	
		Male						
		Beynnon et. al 2014 (12)	1	974	0.0010	0	0.0057	9
		Hewett et. al 1999 (46)	0	225	0	0	0.016	8
		Joseph et. al 2013 (49)	5	1495	0.0033	0.0011	0.0078	8
		Messina et. al 1999 (64)	4	969	0.0041	0.0011	0.011	9
		Stanley et. al 2016 (103)	2	2158	0.00093	0.00023	0.0037	8
		Combined Rate	**12**	**5821**	**0.0025**	**0.0013**	**0.0047**	

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Basketball	Collegiate	Female						
		Agel et. al 2005 [1]	40	25790	0.0016	0.0011	0.0021	8
		Arendt et. al 1999 [7]	38	8602	0.0044	0.0031	0.0061	8
		Beynnon et. al 2014 [12]	1	359	0.0028	0.0001	0.015	9
		Harmon et. al 1998 [43]	34	12296	0.0028	0.0019	0.0039	9
		Laprade and Burnett, 1994 [54]	0	8	0	0	0.37	7
		Mihata et. al 2006 [69]	71	22879	0.0031	0.0024	0.0039	9
		Omi et. al 2018 [77]	4	305	0.013	0.0036	0.033	9
		Stanley et. al 2016 [103]	8	2152	0.0037	0.0019	0.0074	8
		Combined Rate	**196**	**72391**	**0.0043**	**0.0023**	**0.0079**	
		Male						
		Agel et. al 2005 [1]	13	25337	0.00051	0.00030	0.00090	8
		Arendt et. al 1999 [7]	10	8486	0.0012	0.00060	0.0022	8
		Beynnon et. al 2014 [12]	0	360	0	0	0.010	9
		Harmon et. al 1998 [43]	10	11600	0.00086	0.0004	0.0016	9
		Laprade and Burnett, 1994 [54]	0	14	0	0	0.23	7
		Mihata et. al 2006 [69]	22	22298	0.00099	0.0006	0.0015	9
		Stanley et. al 2016 [103]	3	1992	0.0015	0.00049	0.0047	8
		Combined Rate	**58**	**70087**	**0.0016**	**0.00064**	**0.0040**	
	Professional	Female						
		Bonato et. al 2018 [14]	7	67	0.10	0.043	0.20	8
		Deitch et. al 2006 [24]	2	441	0.0045	0.00050	0.016	9
		Trojian et. al 2006 [112]	2	369	0.0054	0.00070	0.019	8
		Vauhnik et. al 2011 [113]	3	38	0.079	0.017	0.21	9
		Combined Rate	**14**	**915**	**0.027**	**0.0075**	**0.096**	
		Male						
		Deitch et. al 2006 [24]	4	698	0.0057	0.0016	0.015	9
		Lombardo et. al 2005 [59]	1	304	0.0033	0.00010	0.0182	9
		Combined Rate	**5**	**1002**	**0.0051**	**0.0021**	**0.0123**	
Dance	Professional	Female						
		Liederbach et. al 2008 [58]	**2**	**117**	**0.018**	**0.0021**	**0.060**	9
		Male						
		Liederbach et. al 2008 [58]	**0**	**62**	**0**	**0**	**0.058**	9
Field Hockey	High School	Female						
		Beynnon et. al 2014 [12]	**1**	**439**	**0.0023**	**0.000058**	**0.013**	9
	Collegiate	Female						
		Beynnon et. al 2014 [12]	**0**	**132**	**0**	**0**	**0.028**	9

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Floorball	High School	Female						
		Pasanen et. al 2018 (82)	**3**	**72**	**0.042**	**0.0087**	**0.12**	8
		Male						
		Pasanen et. al 2018 (82)	**0**	**111**	**0**	**0**	**0.033**	8
	Professional	Female						
		Pasanen et. al 2008 (83)	**3**	**198**	**0.015**	**0.0031**	**0.04**	9
Football	High School	Male						
		Beynnon et. al 2014 (12)	2	1698	0.001	0.00010	0.0042	9
		DeLee et. al 1992 (25)	37	4362	0.0085	0.0060	0.012	9
		Joseph et. al 2013 (49)	57	4943	0.016	0.0087	0.015	8
		Lambson et. al 1996 (53)	14	3305	0.0042	0.0023	0.0071	9
		Meyers et. al 2004 (66)	3	157	0.019	0.004	0.055	8
		Combined Rate	**113**	**14465**	**0.0068**	**0.0032**	**0.014**	
	Collegiate	Male						
		Beynnon et. al 2014 (12)	1	194	0.0052	0.00010	0.028	9
		Dragoo et. al 2012 (29)	64	312878	0.00020	0.00020	0.00030	8
		Meyers et. al 2010 (67)	17	1135	0.015	0.0087	0.024	9
		Combined Rate	**82**	**314207**	**0.0024**	**0.00017**	**0.033**	
Football	Professional	Male						
		Inclan et. al 2021 (Study 1: Mai) (48)	165	18989	0.028	0.026	0.030	9
		Inclan et. al 2021 (Study 2: Okoroha) (48)	130	11364	0.031	0.028	0.034	9
		Inclan et. al 2021 (Study 3:Dodson, Secrist, Yang) (48)	219	7565	0.032	0.028	0.036	9
		Inclan et. al 2021 (Study 4: Johnston) (48)	156	5682	0.031	0.026	0.035	9
		Inclan et. al 2021 (Study 5: Eisenstein) (48)	92	3790	0.030	0.025	0.036	9
		Combined Rate	**762**	**47390**	**0.030**	**0.028**	**0.032**	

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Gymnastics	Collegiate	Female						
		Laprade and Burnett, 1994 [54]	**0**	**6**	**0**	**0**	**0.46**	7
		Male						
		Laprade and Burnett, 1994 [54]	**0**	**8**	**0**	**0**	**0.37**	7
Handball	High School	Female						
		Oshima et. al 2018 [78]	**4**	**100**	**0.040**	**0.011**	**0.099**	9
	Collegiate	Female						
		Petersen et. al 2005 [84]	**5**	**137**	**0.037**	**0.012**	**0.083**	8
	Professional	Female						
		Myklebust et. al 2003 (Year 1) [74]	29	913	0.032	0.021	0.045	9
		Steffen et. al 2016 [105]	4	416	0.0096	0.0026	0.024	8
		Vauhnik et. al 2011 [113]	6	252	0.024	0.0088	0.051	9
		Wedderkopp et. al 1997 [118]	4	205	0.020	0.0053	0.049	8
		Combined Rate	**43**	**1786**	**0.022**	**0.013**	**0.036**	
		Male						
		Seil et. al 1998 [96]	**4**	**182**	**0.022**	**0.0060**	**0.055**	7
Ice Hockey	Collegiate	Female						
		Stanley et. al 2016 [103]	**1**	**1019**	**0.00098**	**0.00014**	**0.0069**	8
		Male						
		Stanley et. al 2016 [103]	**3**	**2117**	**0.0014**	**0.00046**	**0.0044**	8
	Professional	Male						
		Longstaffe et. al 2020 [60]	**7**	**2081**	**0.0034**	**0.0014**	**0.0069**	9
Lacrosse	High School	Female						
		Beynnon et. al 2014 [12]	2	844	0.0024	0.00030	0.0085	9
		Stanley et. al 2016 [103]	6	564	0.011	0.0048	0.023	8
		Combined Rate	**8**	**1408**	**0.0056**	**0.0013**	**0.024**	
		Male						
		Beynnon et. al 2014 [12]	2	988	0.0020	0.0002	0.0073	9
		Stanley et. al 2016 [103]	4	606	0.0066	0.0025	0.017	8
		Combined Rate	**6**	**1594**	**0.0041**	**0.0013**	**0.013**	

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Lacrosse	Collegiate	Female						
		Beynnon et. al 2014 (12)	1	959	0.0010	0	0.0058	9
		Mihata et. al 2006 (69)	10	26486	0.00038	0.00020	0.00070	9
		Stanley et. al 2016 (103)	3	1713	0.00175	0.00056	0.0054	8
		Combined Rate	**14**	**29158**	**0.00078**	**0.00026**	**0.0023**	
		Male						
		Beynnon et. al 2014 (12)	2	1198	0.0017	0.00020	0.0060	9
		Mihata et. al 2006 (69)	11	21733	0.00051	0.00030	0.00090	9
		Stanley et. al 2016 (103)	2	3118	0.00064	0.00016	0.0026	8
		Combined Rate	**15**	**26049**	**0.00066**	**0.00035**	**0.0013**	
Netball	Professional	Female						
		Singh et. al 2013 (99)	**1**	**58**	**0.0014**	**0.00044**	**0.09**	6
Soccer	Recreational	Male						
		Donmez et. al 2018 (28)	**16**	**1022**	**0.016**	**0.0090**	**0.025**	7
	High School	Female						
		Beynnon et. al 2014 (12)	4	634	0.0063	0.0017	0.016	9
		Gupta et. al 2020 (39)	20	107422	0.00019	0.00010	0.00030	9
		Hagglund et. al 2013 (40)	14	2071	0.0068	0.0037	0.011	9
		Heidt et. al 2000 (44)	8	250	0.032	0.014	0.062	7
		Hewett et. al 1999 (46)	2	191	0.010	0.0013	0.034	8
		Joseph et. al 2013 (49)	19	1981	0.0096	0.0058	0.015	8
		LaBella et. al 2011 (52)	6	749	0.0080	0.0029	0.017	8
		Mandelbaum et. al 2005 (62)	34	3784	0.0090	0.0062	0.013	9
		Stanley et. al 2016 (103)	6	1105	0.0054	0.002	0.012	8
		Steffen et. al 2008 (104)	5	942	0.0053	0.0017	0.012	8
		Quisquater et. al 2013 (87)	17	35402	0.00048	0.00030	0.00080	8
		Walden et. al 2012 (116)	14	2071	0.0068	0.0037	0.011	9
		Combined Rate	**149**	**156602**	**0.0048**	**0.0021**	**0.011**	
		Male						
		Beynnon et. al 2014 (12)	1	648	0.0015	0	0.0086	9
		Gupta et. al 2020 (39)	8	40704	0.00020	0.00010	0.00040	9
		Hewett et. al 1999 (46)	1	208	0.0048	0.00010	0.027	8
		Joseph et. al 2013 (49)	9	1991	0.0045	0.0021	0.0086	8
		Stanley et. al 2016 (103)	4	1118	0.041	0.011	0.10	8
		Quisquater et. al 2013 (87)	276	672691	0.0036	0.0013	0.0095	8
		Combined Rate	**299**	**717360**	**0.0013**	**0.00041**	**0.0042**	

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Soccer	Collegiate	Female						
		Agel et. al 2005 [1]	30	40301	0.00074	0.00050	0.0011	8
		Arendt et. al 1999 [7]	19	5263	0.0036	0.00220	0.0056	8
		Beynnon et. al 2014 [12]	3	586	0.0051	0.0011	0.015	9
		Gilchrist et. al 2008 [34]	10	842	0.012	0.0057	0.022	9
		Harmon et. al 1998 [43]	24	15839	0.0015	0.0010	0.0023	9
		Howard et. al 2015 [47]	10	382	0.026	0.013	0.048	9
		Meyers et. al 2013 [68]	4	360	0.011	0.0030	0.028	9
		Mihata et. al 2006 [69]	58	28894	0.0020	0.0015	0.0026	9
		Stanley et. al 2016 [103]	11	3933	0.088	0.045	0.15	8
		Combined Rate	**169**	**96400**	**0.00611**	**0.00223**	**0.0166**	
		Male						
		Agel et. al 2005 [1]	15	45338	0.00033	0.00020	0.00050	8
		Arendt et. al 1999 [7]	16	8743	0.0018	0.0010	0.0030	8
		Beynnon et. al 2014 [12]	2	556	0.0036	0.00040	0.013	9
		Caraffa et. al 1996 [19]	23	277	0.083	0.053	0.12	6
		Harmon et. al 1998 [34]	15	21793	0.00069	0.00040	0.0011	9
		Mihata et. al 2006 [69]	28	31785	0.00088	0.00060	0.0013	9
		Silvers-Granelli et. al 2017 [98]	16	834	0.019	0.011	0.031	9
		Stanley et. al 2016 [103]	2	2492	0.0028	0.0016	0.0050	8
		Combined Rate	**117**	**111818**	**0.0041**	**0.0019**	**0.0086**	
	Professional	Female						
		Faude et. al 2006 [31]	11	132	0.083	0.042	0.14	9
		Faude et. al 2005 [30]	11	154	0.071	0.036	0.12	9
		Giza et. al 2005 [35]	4	198	0.020	0.0055	0.051	7
		Hagglund et. al 2009 [41]	8	220	0.036	0.016	0.070	9
		Larruskain et. al 2018 [55]	1	34	0.029	0.00070	0.153	7
		Le Gall et. al 2008 [56]	2	238	0.0084	0.0010	0.03	9
		Nilstad et. al 2014 [75]	5	168	0.030	0.0097	0.068	8
		Ostenberg and Roos, 2000 [79]	3	120	0.025	0.0052	0.071	8
		Padua et. al 2015 [80]	1	480	0.0021	0.00010	0.012	7
		Roos et. al 1995 [92]	106	36715	0.0029	0.0024	0.0035	9
		Soderman et. al 2000 [101]	1	77	0.013	0.00030	0.070	7
		Soderman et. al 2001 [100]	5	141	0.035	0.012	0.081	8
		Steffen et. al 2016 [105]	4	443	0.0090	0.0025	0.023	8

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Soccer	Professional	Female						
		Tegnander et. al 2008 [110]	2	179	0.011	0.0014	0.040	8
		Quisquater et. al 2013 [87]	3	3122	0.00096	0.00020	0.0028	8
		Walden et. al 2011 [117]	1	309	0.0032	0.00010	0.018	7
		Combined Rate	**168**	**42730**	**0.014**	**0.0073**	**0.027**	
		Male						
		Bjorneboe et. al 2010 [13]	5	149	0.034	0.011	0.077	8
		Grassi et. al 2020 [38]	12	4112	0.0029	0.0015	0.0051	9
		Hagglund et. al 2009 [41]	8	231	0.035	0.015	0.067	9
		Larruskain et. al 2018 [55]	0	50	0	0	0.071	7
		Padua et. al 2015 [80]	0	348	0	0	0.011	7
		Rekik et. al 2018 [89]	7	2236	0.0031	0.0013	0.0064	8
		Rochcongar et. al 2009 [90]	58	44308	0.0013	0.0010	0.0017	8
		Roi et. al 2006 [91]	50	429	0.12	0.088	0.015	8
		Roos et. al 1995 [92]	232	151389	0.0015	0.0013	0.0017	9
		Schiffner et. al 2018 [94]	9	4631	0.0019	0.00090	0.0037	8
		Quisquater et. al 2013 [87]	49	118710	0.0041	0.00030	0.00050	8
		Walden et. al 2011 [117]	3	2016	0.0015	0.00030	0.0043	7
		Combined Rate	**433**	**328609**	**0.0044**	**0.0016**	**0.012**	
Softball & Baseball	High School	Female						
		Joseph et. al 2013 [49]	4	1196	0.0033	0.0013	0.0089	8
		Stanley et. al 2016 [103]	0	2360	0	0	0.0016	8
		Combined Rate	**4**	**3556**	**0.0034**	**0.0014**	**0.0086**	
		Male						
		Joseph et. al 2013 [49]	1	1999	0.00050	0.000070	0.0035	8
		Stanley et. al 2016 [103]	1	2399	0.0084	0.0012	0.057	8
		Combined Rate	**2**	**4398**	**0.0021**	**0.00013**	**0.032**	
	Collegiate	Female						
		Stanley et. al 2016 [103]	**2**	**2598**	**0.020**	**0.0049**	**0.075**	8
		Male						
		Stanley et. al 2016 [103]	**0**	**1650**	**0**	**0**	**0.0022**	8
Rugby	High School	Male						
		Takazawa et. al 2016 [109]	**1**	**289**	**0.0035**	**0.00010**	**0.019**	9
	Collegiate	Female						
		Beynnon et. al 2014 [12]	2	118	0.017	0.0021	0.060	9
		Levy et. al 1997 [57]	5	805	0.0062	0.0020	0.014	9
		Combined Rate	**7**	**923**	**0.0088**	**0.0034**	**0.023**	
		Male						
		Beynnon et. al 2014 [12]	**1**	**119**	**0.0084**	**0.00020**	**0.046**	**9**

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Rugby	Professional	Male						
		Awwad et. al 2019 [9]	2	58	0.0345	0.0042	0.12	7
		Brooks et. al 2005 (Part 1) [16]	4	542	0.0074	0.0020	0.019	8
		Brooks et. al 2005 (Part 2) [17]	1	501	0.0020	0.00010	0.011	8
		Dallalana et. al 2007 [21]	4	542	0.0074	0.0020	0.019	8
		Takazawa et. al 2016 [109]	1	93	0.011	0.00030	0.059	9
		Combined Rate	**12**	**1736**	**0.0089**	**0.0044**	**0.018**	

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Volleyball	High School	Female						
		Hewett et. al 1999 [46]	0	81	0	0	0.045	8
		Joseph et. al 2013 [49]	4	1496	0.0027	0.00070	0.0068	8
		Combined Rate	**4**	**1577**	**0.0029**	**0.0012**	**0.0074**	
	Collegiate	Female						
		Beynnon et. al 2014 [12]	0	45	0	0	0.079	9
	Professional	Female						
		Devetag et. al 2018 [26]	7	1481	0.0047	0.0019	0.0097	8
		Vauhnik et. al 2011 [113]	3	283	0.011	0.0022	0.031	9
		Combined Rate	**10**	**1764**	**0.0063**	**0.0030**	**0.013**	

Sport Type	Level	Author (s) & Year	Number of ACLs Injured Per Season	Number of Non-Injured ACLs per Season	Injury Rate	95% Confidence Interval (LBound)	95% Confidence Interval (UBound)	Risk of Bias
Wrestling	High School	Male						
		Joseph et. al 2013 [49]	**5**	**3495**	**0.0014**	**0.00047**	**0.0033**	8

Table A.1.1: Data extracted from each study

A.2 Table of the Results/Scores of the Risk of Bias Assessment

Study (y)	1	2	3	4	5	6	7	8	9	Total
Agel et. al 2005 (1)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Arendt et. al 1999 (7)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	8
Awwad et. al 2019 (9)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Unclear	7
Beynnon et. al 2014 (12)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Bjorneboe et. al 2010 (13)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Bonato et. al 2018 (14)	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	8
Brooks et. al 2005 (Part 1) (16)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Brooks et. al 2005 (Part 2) (17)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Caraffa et. al 1996 (19)	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	No	Unclear	6
Dallalana et. al 2007 (21)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Deitch et. al 2006 (24)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
DeLee et. al 1992 (25)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Devetag et. al 2018 (26)	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	8
Donmez et. al 2018 (28)	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	No	7
Dragoo et. al 2012 (29)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	8
Faude et. al 2006 (31)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Faude et. al 2005 (30)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Gilchrist et. al 2008 (34)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Giza et. al 2005 (35)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Unclear	7
Gomez et. al 1996 (36)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Grassi et. al 2020 (38)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9

Gupta et. al 2020 (39)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Haida et. al 2016 (42)	Yes	Yes	Yes	Yes	Yes	Unclear	Unclear	Yes	Yes	7
Hagglund et. al 2013 (40)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Hagglund et. al 2009 (41)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Harmon et. al 1998 (43)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Heidt et. al 2000 (44)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Unclear	7
Hewett et. al 1999 (46)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Howard et. al 2015 (47)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Inclan et. al 2021 (48)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Joseph et. al 2013 (49)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
LaBella et. al 2011 (52)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Lambson et. al 1996 (53)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Laprade and Burnett, 1994 (54)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Unclear	7
Larruskain et. al 2018 (55)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Unclear	7
Le Gall et. al 2008 (56)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Levy et. al 1997 (57)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Liederbach et. al 2008 (58)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Lombardo et. al 2005 (59)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Longstaffe et. al 2020 (60)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Mandelbaum et. al 2005 (62)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Messina et. al 1999 (64)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Meyers et. al 2004 (66)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Meyers et. al 2010 (67)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9

Meyers et. al 2013 (68)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Mihata et. al 2006 (69)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Myklebust et. al 2003 (Year 1) (74)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Nilstad et. al 2014 (75)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Omi et. al 2018 (77)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Oshima et. al 2018 (78)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Ostenberg and Roos, 2000 (79)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Padua et. al 2015 (80)	Yes	Unclear	No	Yes	Yes	Yes	Yes	Yes	Yes	7
Pasanen et. al 2018 (82)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Pasanen et, al 2008 (83)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Petersen et. al 2005 (84)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Pujol et. al 2007 (86)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Raschner et. al 2012 (88)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Rekik et. al 2018 (89)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Rochcongar et. al 2009 (90)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Roi et. al 2006 (91)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Roos et. al 1995 (92)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Scranton et. al 1997 (95)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Seil et. al 1998 (96)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Unclear	7
Silvers-Granelli et. al 2017 (98)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Singh et. al 2013 (99)	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	6
Soderman et. al 2000 (101)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	7

Soderman et. al 2001 (100)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Stanley et. al 2016 (103)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Steffen et. al 2008 (104)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Steffen et. al 2016 (105)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Takazawa et. al 2016 (109)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
Tegnander et. al 2007 (110)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Trojian et. al 2006 (112)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	8
Quisquater et. al 2013(87)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	8
Viola et. al 1999 (115)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9

Table A.2.1: Results of the Risk of Bias Assessment Using the Joanna Briggs Institute Critical Appraisal tools for use in JBI Systematic Reviews

A.3 Figure of the JBI Critical Appraisal Checklist

THE JOANNA BRIGGS INSTITUTE

JBI Critical Appraisal Checklist for Studies Reporting Prevalence Data

Reviewer____________________________________Date__________________________________

Author ____________________________________Year_________Record Number____________

	Yes	No	Unclear	Not applicable
1. Was the sample frame appropriate to address the target population?	☐	☐	☐	☐
2. Were study participants sampled in an appropriate way?	☐	☐	☐	☐
3. Was the sample size adequate?	☐	☐	☐	☐
4. Were the study subjects and the setting described in detail?	☐	☐	☐	☐
5. Was the data analysis conducted with sufficient coverage of the identified sample?	☐	☐	☐	☐
6. Were valid methods used for the identification of the condition?	☐	☐	☐	☐
7. Was the condition measured in a standard, reliable way for all participants?	☐	☐	☐	☐
8. Was there appropriate statistical analysis?	☐	☐	☐	☐
9. Was the response rate adequate, and if not, was the low response rate managed appropriately?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

Figure A.3.1: JBI Critical Appraisal Checklist for Studies Reporting Prevalence Data

Figure A.3.2: JBI Critical Appraisal Checklist for Studies Reporting Prevalence Data