Effect of neuromuscular injury prevention strategies on injury rates in adolescent males playing sport: a systematic review protocol

Olivier, Franso-Mari[1,*]; Olivier, Benita[1,2]; MacMillan, Candice[1,3]; Briel, Sonia[4]

[1]Wits Cricket Research Hub for Science, Medicine and Rehabilitation, Department of Physiotherapy, School of Therapeutic Sciences, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa

[2]The Wits-JBI Centre for Evidenced-Based Practice: A JBI Affiliated Group, University of Witwatersrand, Johannesburg, South Africa

[3]Sport, Exercise Medicine, and Lifestyle Institute (SEMLI), Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa

[4]Department of Physiotherapy, School of Therapeutic Sciences, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa

The authors declare no conflict of interest.

Correspondence: Franso-Mari Olivier, fransomari@gmail.com

Abstract

Objective: This review will assess the effectiveness of neuromuscular injury prevention strategies on injury rates among adolescent males playing sports.

Introduction: Adolescent athletes are predisposed to injuries during this period of growth. Growth-related injury risk factors can be mitigated by implementing appropriate neuromuscular injury prevention strategies. This review will include all sporting disciplines in summarizing the components and assessing the effectiveness of injury prevention strategies in the adolescent male population.

Inclusion criteria: Randomized controlled trials investigating adolescent males, between the ages of 13 and 18 years, participating in organized sports, in any setting and level of participation, will be included. Studies that evaluate neuromuscular injury prevention strategies (eg, balance, proprioceptive, plyometric, agility, strength, weight, conditioning and sport-specific exercises and training, warm up, cool down, stretches, neuromuscular control) vs no intervention or standard training and competition exposure will be included. The outcomes of interest are injury incidence and prevalence rates.

Methods: Databases searched will include MEDLINE (PubMed), CINAHL Complete (EBSCOhost), ClinicalKey, SPORTDiscus (EBSCOhost), Physiotherapy Evidence Database (PEDro), Scopus, ScienceDirect, MasterFILE Premier (EBSCOhost), Academic Search Complete (EBSCOhost), Cochrane Central Register of Controlled Trials (CENTRAL) and ClinicalTrials.gov. Gray literature and unpublished studies will be searched via Health and Medical Complete (ProQuest Dissertations & Theses). Study screening and selection against inclusion criteria will

be performed. Data extraction and critical appraisal will be performed using the standardized JBI templates and checklists for qualitative research. All stages will be performed by 2 independent reviewers, with conflicts resolved by a third reviewer.

Review registration: PROSPERO CRD42022327047

Keywords: adolescent male; growth spurt; neuromuscular injury prevention; systematic review; youth sport

Introduction

Adolescents experience measurable changes in anthropometrics, body composition, or the size of specific regions in the body from age 10 to 20 years.[1] Maturation describes the functional and structural system changes contributing to a mature state. Growth and maturation may be used interchangeably, with growth being a constantly evolving process and maturation having a definite end point.[2] The 2 processes occur at different rates among individuals.[1]

The onset and process of adolescence follow different paths in male and female bodies. The maximal linear growth tempo is peak height velocity, and is generally observed around 14 years of age in boys and 12 years of age in girls, with annual average gains of 9 cm and 8 cm, respectively.[3] Body composition (in terms of fat mass, fat-free mass, and body fat distribution) also differs between sexes. During early (10 to 13 years of age) and middle adolescence (14 to 16 years of age), both sexes experience increases in fat mass and fat-free mass. Females are also more flexible than their male counterparts. Males experience a decrease in flexibility leading up to mid-adolescence, approximately around 14 to 15 years of age; in contrast, females' flexibility increases slightly and then plateaus, similar to muscle strength.[3] Muscle-strength gains among males accelerate around the age of 13. Injury rates also differ vastly between sexes, with males reporting rates of injuries nearly twice as high as females (23.8% vs 12.4%).[4]

Periods of rapid growth (ie, growth spurts) are interspersed with plateaus. Growth spurts are considered a risk factor for sports injuries,[5] and adolescent athletes are more susceptible to overuse and growth plate–related injuries.[6] Additional factors, such as decreased bone mineral density, increased tensile forces on vulnerable muscle attachments, decreased neuromuscular control, reduced flexibility,[7] changes in center of mass, a transient reduction or loss of skill, and rapidly increasing training volumes, further increase risk of injury during this time.[8]

Consistent adherence to appropriate injury prevention programs may protect adolescents from sustaining injuries. These strategies include pre-participation screening, minimizing training errors, technique correction, delaying specialization in a single sport, adequate rest and recovery, avoiding overscheduling, monitoring and modification of training during growth spurts, and appropriate education for parents and coaches.[9]

Exercise-based injury prevention programs have successfully modified neuromuscular risk factors and reduced injuries across a wide variety of sports.[10] Injury prevention programs among adolescent cricket pace bowlers include strength-training regimes, prescription of bowling volume, and modification of bowling mechanics.[11] Traditionally, stretching (passive, static, ballistic, isometric, and proprioceptive neuromuscular facilitation) has been included in warm-up and cool-down routines to improve athletes' flexibility and reduce injury risk; however, findings regarding the efficacy of stretching are inconclusive.[12] Neuromuscular training is widely supported as an effective intervention strategy for reducing injury risk.[13]

A preliminary search of PROSPERO, MEDLINE, the Cochrane Database of Systematic Reviews, and *JBI Evidence Synthesis* was conducted, and no current or in-progress systematic reviews were identified that investigate neuromuscular injury prevention strategies for adolescent males playing sport. A systematic review was published in 2007,[14] but limits on language (English) and sporting discipline were applied, excluding "minority sports" and "extreme sport." Other reviews focused only on a single intervention, such as exercise.[10] This study will include all languages, sports, and neuromuscular training as injury prevention strategies.

The objective of this review is to assess the effectiveness of neuromuscular training strategies to mitigate injury rates among adolescent male athletes. This review will summarize the components of current neuromuscular training strategies (eg, balance, proprioceptive, plyometric, agility, strength, weight, conditioning and sport-specific exercises and training, warm up, cool down, stretches and neuromuscular control) utilized as injury prevention programs in adolescent sport and the methods used for evaluating the programs' effectiveness. These results can be used to inform stakeholders (eg, coaches, players) about best current practices (or lack thereof) aimed at addressing injury risk among adolescent male athletes (see Appendix I for definitions).

Review question

What is the effectiveness of neuromuscular injury prevention strategies vs standard training on the number of injuries in adolescent males playing sport?

Inclusion criteria

Participants

This review will include studies on adolescent males between 13 and 18 years of age, of all body mass index (BMI) percentiles and categories (underweight, normal weight, overweight), participating in all sporting disciplines from recreational to elite levels. *Youth sport* includes activities designed and/or organized for children or youth. *Sport* will be defined according to PubMed's Medical Subject Headings (MeSH) description: "activities or games, usually involving physical effort or skill. Reasons for engagement in sports include pleasure, competition or financial reward."

Studies reporting on participants with growth abnormalities or diseases, such as endocrine disorders (growth hormone deficiency, hypothyroidism, and hypoparathyroidism) or severe childhood conditions (cystic fibrosis, Crohn's disease, and cancer), reducing bone mass and

increasing risk of fractures or abnormal skeletal growth, will be excluded. Considering the influence of sex-related anthropometric differences on injury risk and sports performance, females will be excluded in this study.

Intervention

Studies that evaluate neuromuscular injury prevention strategies for adolescent males participating in sport will be included. These programs are typically multifaceted. Strategies will include, but not be limited to, balance, proprioceptive, plyometric, agility, strength, weight, conditioning and sport-specific exercises and training, warm up, cool down, stretches, and neuromuscular control.[15] All eligible studies will be included, regardless of intervention frequency, dosage, or method of delivery. Interventions delivered by any sports trainers, physiotherapists, researchers, or research assistants will be considered. The following interventions will be excluded: nutrition, strapping, bracing, protective gear (eg, helmets, shin guards, mouth guards), virtual reality exercises, orthotics, training and competition volume management, technique modification, education, rest and recovery, screening, injury surveillance, and delayed specialization.

Comparator

This review will consider studies that compare neuromuscular training interventions to age-matched control groups receiving no intervention or standard, routine training and competition exposure.

Standard training and competition exposure refers to no intervention, no change to the training, or practice that the group would typically be receiving. If the group implementing standard training consists of elements similar to those in the intervention, those elements will be treated as standard strategy, and only the elements not part of the standard training will be measured for the effectiveness of preventing injury.

Outcomes

The primary outcome measures of interest are the injury incidence (per 1000 athlete hours) and prevalence rates (proportion of athletes per time period). A *sports injury* involves tissue damage or other derangements of normal physical function due to participation in sports, resulting from rapid or repetitive transfer of kinetic energy.[16] Secondary outcome measures may include the type (measured as categorical data) of injuries (acute and chronic) obtained after the intervention, as well as the severity.

This systematic review will adopt the following definitions. An *acute injury* is obtained during a single, identifiable traumatic event where tissue is stressed and strained by a force greater than what the tissue can withstand.[17]*Overuse* or *chronic* injuries are obtained during repetitive stress and cumulative trauma.[18]*Severity* of sports injuries will be described as slight (0 days absent, able to participate fully in next match or training), minor (absent from match or training 1 to 7 days), moderate (absent from match or training 8 to 21 days), or major (absent from match or training more than 21 days).[19]

Types of studies

This review will only include randomized controlled trials.

Methods

The proposed systematic review will be conducted according to the JBI methodology for systematic review of effectiveness[20] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[21] This protocol has been registered in PROSPERO (CRD42022327047). Any deviations from the protocol will be explained in the final review.

Search strategy

A 3-step search strategy will be conducted to find published and unpublished studies. Firstly, an initial search was conducted in MEDLINE via PubMed. The search strategy was trialed to refine it by removing duplicate or inadequate search terms and retesting as necessary to ensure that it was sufficiently sensitive to identify all relevant studies. Secondly, the search strategy will then be adapted for each database searched. Keywords will be searched in titles and abstracts, index terms, and, where possible, MeSH terms (see Appendix II for a sample search strategy for MEDLINE via PubMed). Thirdly, a search will be performed on the reference lists of the included studies to identify any additional studies to be included in the review.

No language filters will be applied. Google Translate will be used for studies in languages other than English to assess them for inclusion based on title, abstract, and full text. A professional translator will translate the full text to ensure accurate extraction of data.

The following databases will be searched from inception to the present with a human: MEDLINE (PubMed), CINAHL Complete (EBSCOhost), ClinicalKey, SPORTDiscus (EBSCOhost), Physiotherapy Evidence Database (PEDro), Scopus, ScienceDirect, MasterFILE Premier (EBSCOhost), Health and Medical Complete (ProQuest), Academic Search Complete (EBSCOhost), Cochrane Central Register of Controlled Trials (CENTRAL), ClinicalTrials.gov, ProQuest Dissertations and Theses, MedNar, OpenGrey (SIGLE), Worldwidescience.org, Google Scholar, and WorldCat. Due to the large volume of results provided by Google Scholar, and the limited ability to narrow results down when using the advanced search function, the reviewers will consider the first 1000 results. Theses and dissertations found in gray literature databases will be included in the review. Further, known experts will be contacted to identify any additional publications.

Study selection

All identified citations will be collated and uploaded to EndNote v.20 (Clarivate Analytics, PA, USA) and duplicates removed. Two or more independent reviewers will screen titles and abstracts against the inclusion criteria for the review. A pilot will be undertaken to familiarize the reviewers with the process and criteria. Potentially relevant studies will be retrieved in full, and their details imported into the JBI System for the Unified Management, Assessment and Review of Information (JBI SUMARI; JBI, Adelaide, Australia).[22] Two independent

reviewers will then screen full-text articles against the inclusion criteria. Full-text articles that do not meet the inclusion criteria will be excluded, and reasons for exclusion will be reported in the systematic review. Any disagreements between the reviewers will be resolved through discussion or with a third reviewer. The search results and the study inclusion process will be reported in full in the final systematic review and presented in a PRISMA flow diagram.[21]

Assessment of methodological quality

Two independent reviewers will independently assess eligible studies for methodological quality using the JBI critical appraisal tool for experimental studies (randomized controlled trials). Any disagreements will be discussed with a third reviewer.[20,22] This standardized critical appraisal tool consists of 13 items, each requiring a dichotomous yes/no response. A "yes" response is allocated 1 point, and a "no" response 0 points. An "unclear/not applicable" will not be allocated any points and the total number of points will be adapted to account for the "unclear/not applicable" options. Methodological quality for randomized controlled trails will be assigned as follows: studies scoring 1–5 (low quality), 6–10 (moderate quality), and 11–13 (high quality). All studies, irrespective of methodological quality, will be included. The results of critical appraisal will be reported in a table with accompanying narrative, and methodological quality will be considered when conclusions are drawn.

Data extraction

The standardized JBI SUMARI data extraction tool[20,23] will be used to extract data from the eligible studies by 2 independent reviewers. Extracted data will be presented in a table, including details about authors and articles (names, article title, year of publication, and source); participants (number of participants, level of sport participation, country, sport discipline, ages of participants); study methods (randomized controlled trials); neuromuscular injury prevention interventions (intervention type, content, timing, nature of implementation [ie, number of training sessions, frequency of program, dosages, duration of a program]); compliance (ie, percentage attended, sessions attended, role of the person delivering the sessions); outcomes (injury rates/incidence, severity of injury, acute vs chronic); and critical appraisal rating.

Two reviewers will pilot data extraction to familiarize themselves with the tool, evaluate appropriateness thereof, and minimize data extraction errors; data will then be extracted independently. The reviewers will resolve any disagreements through discussion or arbitration by a third reviewer. Confounding factors (age, BMI, socioeconomic status, comorbidities, growth spurt status, additional sports participation, or different definitions used for injury outcomes) reported by the included studies will also be extracted and accounted for. Where required, missing or additional data will be requested from the authors of papers. In cases where no response is obtained from an author, a reminder email will be sent 10 days after the initial email.

Data synthesis

A statistical meta-analysis, using JBI SUMARI, will pool quantitative data, if possible. A narrative method, using tables and graphs, may be utilized to represent data if pooling is not

possible. Proportion-based effect sizes will be expressed as relative risk, odds ratios, or weighted, and prevalence will be calculated using a random or fixed effects model and mean differences for continuous data (injury incidence and prevalence rates).[24] For the analysis of effect sizes, the 95% CI will be calculated. Categorical data (type of injury and severity) will be analyzed using χ^2 probability distribution.

A sensitivity analysis will be performed to investigate the robustness of the results and the variance in study design, statistical methods, and methodology. Subgroup analyses will be performed to test the different cluster adjustment methods, performing synthesis using various statistical models, methods, and effect measures. The inclusion of the methodological quality of studies will also be assessed. Similarity regarding the effect magnitude and direction will be ascertained by this testing and illustrated in a forest plot. Statistical heterogeneity will be identified by the standard Cochran's Q and its *P* value, together with the χ^2 statistical assessments. The heterogeneity will be quantified by the I^2 and T^2 statistical tests. The thresholds for heterogeneity will be classified as unimportant (0 to 40%), moderate (30% to 60%), substantial (50% to 90%), and considerable (75% to 100%). The significance of the clinical heterogeneity will be indicated by a lower *P* value, bearing in mind that the *P* value's significance is set at 0.1, due to the statistical test's low power.[25] Sufficient data could allow for subgroup analyses, including different components of neuromuscular injury prevention programs; different sporting disciplines; acute vs chronic injuries; and confounding factors, such as BMI, as discussed in data extraction. Subgroups will enable the comparison of the effect and effectiveness of the different components, between different sporting disciplines; acute and chronic injuries; and elite vs recreational levels of sport. A funnel plot will be generated using the statistical program IBM SPSS Statistics 28.0.1 (Armonk, NY: IBM Corp), and statistical tests for asymmetry (Egger test, Begg test, Harbord test) will be performed, where appropriate.[24]

Assessing certainty in the findings

The Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach for grading the certainty of evidence will be followed.[26] A Summary of Findings (SoF) will be created using GRADEpro GDT (McMaster University, ON, Canada).[27] Two independent reviewers will compile this, and disagreements will be resolved through discussion or with a third reviewer. The SoF will present the following information, where appropriate: estimates of relative risk, a ranking of the quality of the evidence based on the risk of bias, directness, heterogeneity, precision, and risk of publication bias of the review results. The outcomes reported in the SoF will be injury incidence (per 1000 athlete hours), prevalence rates (proportion of athletes per time period), and severity of injury (time lost).

Acknowledgments

This review will contribute toward a doctorate in philosophy through the University of the Witwatersrand for FO.

Funding

Funding was received by FO from the South African Society of Physiotherapy. The funders will have no role in the review process.

Author contributions

FO, BO, CM contributed to the review design. FO and SB will perform the literature screening, appraisal, and data extraction. FO will perform the analysis and writing of the manuscript. BO and CM contributed to the manuscript as supervisors.

References

1. Brown KA, Patel DR, Darmawan D. Participation in sports in relation to adolescent growth and development. Transl Pediatr 2017;6(3):150.
2. Beunen G, Malina R. The young athlete: relevance to athletic performance In: Hebestreit H, editor. Encyclopaedia of Sports Medicine. Blackwell Publishing; 2008:3–17.
3. Kreipe RE. Textbook of Adolescent Medicine. W B Saunders; 1994:24.
4. LeBrun DG, Del Rosario J, Kelly JD, Wren SM, Spiegel DA, Mkandawire N, et al. An estimation of the burden of sports injuries among African adolescents. J Epidemiol Glob Health 2018;8(3-4):171.
5. Johnson DM, Williams S, Bradley B, Sayer S, Murray Fisher J, Cumming S. Growing pains: maturity associated variation in injury risk in academy football. Eur J Sport Sci 2020;20(4):544–552.
6. Jayanthi N, Schley S, Cumming SP, Myer GD, Saffel H, Hartwig T, et al. Developmental training model for the sport specialized youth athlete: a dynamic strategy for individualizing load-response during maturation. Sports Health 2022;14(1):142–153.
7. McKay D, Broderick C, Steinbeck K. The adolescent athlete: a developmental approach to injury risk. Pediatr Exerc Sci 2016;28(4):488–500.
8. Patel TS, McGregor A, Williams K, Cumming SP, Williams S. The influence of growth and training loads on injury risk in competitive trampoline gymnasts. J Sports Sci 2021;39(23):2632–2641.
9. DiFiori JP. Evaluation of overuse injuries in children and adolescents. Curr Sports Med Rep 2010;9(6):372–378.
10. Rossler R, Donath L, Verhagen EALM, Junge A, Schweizer T, Faude O. Exercise-based injury prevention in child and adolescent sport: a systematic review and meta-analysis. Sports Med 2014;44(12):1733–1748.
11. Forrest MRL, Scott Brendan R, Hebert Jeffrey J, Dempsey Alasdair R. Injury prevention strategies for adolescent cricket pace bowlers. Sports Med 2018;48(11):2449–2461.
12. Thacker SB, Gilchrist J, Stroup DF, Kimsey CD Jr. The impact of stretching on sports injury risk: a systematic review of the literature. Med Sci Sports Exerc 2004;36(3):371–378.
13. Emery CA, Pasanen K. Current trends in sport injury prevention. Best Pract Res Clin Rheumatol 2019;33(1):3–15.
14. Abernethy L, Bleakley C. Strategies to prevent injury in adolescent sport: a systematic review. Br J Sports Med 2007;41(10):627–638.
15. Hübscher M, Zech A, Pfeifer K, Hänsel F, Vogt L, Banzer W. Neuromuscular training for sports injury prevention: a systematic review. Med Sci Sport Exercise 2010;42(3):413–421.

16. Bahr R, Clarsen B, Derman W, Dvorak J, Emery CA, Finch CF, et al. International Olympic Committee Consensus Statement: methods for recording and reporting of epidemiological data on injury and illness in sports 2020 (including the STROBE Extension for Sports Injury and Illness Surveillance (STROBE-SIIS)). Orthop J Sports Med 2020;8(2):2325967120902908.
17. Stuart W. Sports injuries: acute. In: Brukner P, editor. Clinical sports medicine, 5th ed. McGraw-Hill Education (Australia) Pty Ltd; 2017:13.
18. Yang J, Tibbetts AS, Covassin T, Cheng G, Nayar S, Heiden E. Epidemiology of overuse and acute injuries among competitive collegiate athletes. J Athl Train 2012;47(2):198–204.
19. Olsen O-E, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. BMJ 2005;330(7489):449.
20. Tufanaru C, Munn Z, Aromataris E, Campbell J, Hopp L. Chapter 3: Systematic reviews of effectiveness. In: Aromataris E, Munn Z, editors. JBI Manual for Evidence Synthesis [internet]. JBI; 2020 [cited 2020 May 30]. Available from: https://synthesismanual.jbi.global.
21. Page MJ, McKenzie JE, Bossuyt PM, Bourton I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71.
22. Munn Z, Aromataris E, Tufanaru C, Stern C, Porritt K, Farrow J, et al. The development of software to support multiple systematic review types: the Joanna Briggs Institute System for the Unified Management, Assessment and Review of Information (JBI SUMARI). Int J Evid Based Healthc 2019;17(1):36–43.
23. Munn Z, Tufanaru C, Aromataris E. JBI's systematic reviews: data extraction and synthesis. Am J Nurs 2014;114(7):6.
24. Tufanaru C, Munn Z, Stephenson M, Aromataris E. Fixed or random effects meta-analysis? Common methodological issues in systematic reviews of effectiveness. Int J Evid Based Healthc 2015;13(3):196–207.
25. Fletcher J. What is heterogeneity and is it important? BMJ 2007;334(7584):94–96.
26. Guyatt G, Oxman AD, Akl EA, Kunz R, Vist G, Brozek J, et al. GRADE guidelines: 1. Introduction—GRADE evidence profiles and summary of findings tables. J Clin Epidemiol 2011;64(4):383–394.
27. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 2008;336(7650):924–926.

Appendix I: Definitions of terms to be used in the systematic review

Participants	
Adolescents	Any person between 10 and 19 years of age is referred to as an adolescent by the World Health Organization (https://www.who.int/health-topics/adolescent-health)
Definitions	
Athlete	An athlete is an individual who is formally registered with a sport federation – in this case a club or school – attempting to improve skill, performance, and results by being actively engaged in sports training to compete. Training and competition are the main physical activities and several hours are devoted to it.
Sport	Sport will be defined as an activity or game where physical effort and skill is required. Participation in sport could be for pleasure, to compete, or for financial gain.
Organized sport	Organized sport is defined by the degree of structure in organizations, surrounding and influencing sport. This will determine whether it is an activity or 'organized sport.
Interventions: included	
Agility training	Agility is the body's ability to rapidly change direction, accelerate, or decelerate. It is influenced by balance, strength, coordination, and skill level.
Balance	Balance control is the ability to maintain the body's center of mass within the limits of the supporting base.
Cool down	A low- to moderate-intensity exercise or movement performed within 1 hour after training and competition
Neuromuscular injury prevention strategies	Balance, proprioceptive, plyometric, agility, strength, weight training, conditioning and sport-specific exercises and training, warm up, cool down, stretches, massage, manual therapy and neuromuscular core control
Plyometric training	The stretch reflex is increased by muscles repeatedly and rapidly stretching, followed by shortening, concentric contraction (eg, jumping and rebounding).
Proprioception	Proprioceptive receptors in joints, tendons, muscles, and the inner ear transduce stimuli into neural impulses to the central nervous system. Proprioception is the sense of stationary positions and movements of body parts and is important in maintaining kinesthesia and postural balance.
Sport-specific exercises	Sport-specific exercises are fitness and performance training designed specifically for athletic performance enhancement.
Strength and weight training	Strength training (also known as resistance exercise) increases muscle strength by making muscles work against a weight or force and is a form of anaerobic exercise.
Stretches	Exercises that stretch the muscle fibers to increase muscle-tendon flexibility, improve range of motion or musculoskeletal function, and prevent injuries. Types of stretching techniques include active, passive (relaxed), static, dynamic (gentle), ballistic (forced) and isometric.
Warm up	Warm up is a period of preparatory exercise to enhance subsequent competition or training performance.
Interventions: excluded	

Nutrition, pre-participation screening, delayed specialization, protective measures (strapping and bracing) and equipment (helmets, mouth guards, shin guards, padding), virtual reality exercises, orthotics, training and competition volume management, technique modification, education, rest and recovery, injury surveillance	
Comparators	
Standard competition exposure	Standard competition exposure refers to no change in the standard/normal/routine amount/level of competition, hence, taking part in the usual amount or type of competition.
Standard training	Standard training refers to no intervention, no change to the training or practice that group would normally be receiving.
Outcomes	
Injury	A sports injury involves tissue damage or other derangements of normal physical function due to participation in sports, resulting from rapid or repetitive transfer of kinetic energy.
Acute injury	An acute injury is obtained during a single, identifiable traumatic event where tissue is stressed and strained by a force greater than what the tissue can withstand.
Chronic injury	Overuse or chronic injuries are obtained during repetitive stress and cumulative trauma.
Severity of injury (categorical data: slight, minor, moderate, major; continuous data: time lost)	Severity of sports injuries will be described as: slight (0 days absent, able to participate fully in next match or training), minor (absent from match or training 1-7 days), moderate (absent from match or training 8-21 days), and major (absent from match or training more than 21 days).
Injury incidence	Incidence is an expression of risk. Incidence rates describe the number of new injuries that occur in a population at risk over a specific period of time, or the number of new injuries during a period divided by the total number of sportspeople at that period.
Injury prevalence	Prevalence refers to the proportion of individuals in a population who have an injury at a particular time.

Appendix II: Search strategy

MEDLINE (PubMed)

Search conducted: October 24, 2023

Total records retrieved: 770

Search	Query	Records retrieved
#1	adolescent [mh] OR "adolescent development" [mh] OR teen [tw] OR teenager [tw] OR Adolescents [tw] OR teens [tw] OR youth [tw] OR youths [tw] OR adolescence[All Fields] OR adolescent [All Fields] OR teenager [All Fields] OR teenagers[All Fields] OR teen[tw] Filter: Human ("adolescent"[MeSH Terms] OR "adolescent development"[MeSH Terms] OR "teen"[Text Word] OR "teenager"[Text Word] OR "Adolescents"[Text Word] OR "teens"[Text Word] OR "youth"[Text Word] OR "youths"[Text Word] OR "adolescences"[All Fields] OR "adolescency"[All Fields] OR "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "adolescence"[All Fields] OR "Adolescents"[All Fields] OR "adolescent s"[All Fields] OR "adolescences"[All Fields] OR "adolescency"[All Fields] OR "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "adolescence"[All Fields] OR "Adolescents"[All Fields] OR "adolescent s"[All Fields] OR "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "teenage"[All Fields] OR "teenager"[All Fields] OR "teenagers"[All Fields] OR "teenaged"[All Fields] OR "teenager s"[All Fields] OR "teenages"[All Fields] OR "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "teenage"[All Fields] OR "teenager"[All Fields] OR "teenagers"[All Fields] OR "teenaged"[All Fields] OR "teenager s"[All Fields] OR "teenages"[All Fields] OR "teen"[Text Word]) AND (humans[Filter]) **Translations adolescent [mh]:** "adolescent"[MeSH Terms] **adolescence[All Fields]:** "adolescences"[All Fields] OR "adolescency"[All Fields] OR "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "adolescence"[All Fields] OR "adolescents"[All Fields] OR "adolescent's"[All Fields] **adolescent [All Fields]:** "adolescences"[All Fields] OR "adolescency"[All Fields] OR "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "adolescence"[All Fields] OR "adolescents"[All Fields] OR "adolescent's"[All Fields] **teenager [All Fields]:** "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "teenage"[All Fields] OR "teenager"[All Fields] OR "teenagers"[All Fields] OR "teenaged"[All Fields] OR "teenager's"[All Fields] OR "teenages"[All Fields] **teenagers[All Fields]:** "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "teenage"[All Fields] OR "teenager"[All Fields] OR "teenagers"[All Fields] OR "teenaged"[All Fields] OR "teenager's"[All Fields] OR "teenages"[All Fields]	2,297,378
#2	sports [mh] OR Athletic Performance [mh] OR baseball [mh] OR basketball [mh] OR bicycling [mh] OR boxing [mh] OR Boxing [mh] OR cricket sport [mh] OR cricket sport [mh] OR Cricket Sport [tw] OR football [mh] OR Football [tw] OR golf [mh] OR Golf [tw] OR gymnastics [mh] OR Gymnastics [tw] OR hockey [mh] OR Hockey [tw] OR martial arts [mh] OR Martial Arts [tw] OR "tai ji" [mh] OR "Tai Ji" [tw] OR Mountaineering [tw] OR "racquet sports"[mh] OR Racquet Sports [tw] OR "tennis"[mh] OR Tennis [tw] OR "return to sport"	282,182

	[mh] OR “Return to Sport” [tw] OR “rugby”[mh] OR Rugby [tw] OR running [mh] OR Running [tw] OR jogging [mh] OR Jogging [tw] OR “marathon running” [mh] OR “Marathon Running” [tw] OR skating [mh] OR Skating [tw] OR “snow sports” [mh] OR “Snow Sports” [tw] OR skiing [mh] OR Skiing [tw] OR soccer [mh] OR Soccer [tw] OR “team sports”[mh] OR Team Sports [tw] OR “track and field” [mh] OR “Track and Field” [tw] OR “volleyball” [mh] OR Volleyball [tw] OR walking [mh] OR Walking [tw] OR “nordic walking” [mh] OR “Nordic Walking” [tw] OR “water sports” [mh] OR “Water Sports” [tw] OR swimming [mh] OR Swimming [tw] OR “weight lifting” [mh] OR “Weight Lifting” [tw] OR wrestling [mh] OR Wrestling [tw] OR “youth sports” [mh] OR “Youth sports“ [tw] OR “diving”[mh] OR diving[tw] Filter: Human (“Sports”[MeSH Terms] OR “athletic performance”[MeSH Terms] OR “baseball”[MeSH Terms] OR “basketball”[MeSH Terms] OR “bicycling”[MeSH Terms] OR “boxing”[MeSH Terms] OR “boxing”[MeSH Terms] OR “cricket sport”[MeSH Terms] OR “cricket sport”[MeSH Terms] OR “cricket sport”[Text Word] OR “Football”[MeSH Terms] OR “Football”[Text Word] OR “Golf”[MeSH Terms] OR “Golf”[Text Word] OR “Gymnastics”[MeSH Terms] OR “Gymnastics”[Text Word] OR “Hockey”[MeSH Terms] OR “Hockey”[Text Word] OR “martial arts”[MeSH Terms] OR “martial arts”[Text Word] OR “Tai Ji”[MeSH Terms] OR “Tai Ji”[Text Word] OR “Mountaineering”[Text Word] OR “racquet sports”[MeSH Terms] OR “racquet sports”[Text Word] OR “Tennis”[MeSH Terms] OR “Tennis”[Text Word] OR “Return to Sport”[MeSH Terms] OR “Return to Sport”[Text Word] OR “Rugby”[MeSH Terms] OR “Rugby”[Text Word] OR “Running”[MeSH Terms] OR “Running”[Text Word] OR “Jogging”[MeSH Terms] OR “Jogging”[Text Word] OR “Marathon Running”[MeSH Terms] OR “Marathon Running”[Text Word] OR “Skating”[MeSH Terms] OR “Skating”[Text Word] OR “Snow Sports”[MeSH Terms] OR “Snow Sports”[Text Word] OR “Skiing”[MeSH Terms] OR “Skiing”[Text Word] OR “Soccer”[MeSH Terms] OR “Soccer”[Text Word] OR “team sports”[MeSH Terms] OR “team sports”[Text Word] OR “Track and Field”[MeSH Terms] OR “Track and Field”[Text Word] OR “Volleyball”[MeSH Terms] OR “Volleyball”[Text Word] OR “Walking”[MeSH Terms] OR “Walking”[Text Word] OR “Nordic Walking”[MeSH Terms] OR “Nordic Walking”[Text Word] OR “Water Sports”[MeSH Terms] OR “Water Sports”[Text Word] OR “Swimming”[MeSH Terms] OR “Swimming”[Text Word] OR “Weight Lifting”[MeSH Terms] OR “Weight Lifting”[Text Word] OR “Wrestling”[MeSH Terms] OR “Wrestling”[Text Word] OR “Youth sports”[MeSH Terms] OR “Youth sports”[Text Word] OR “diving”[MeSH Terms] OR “diving”[Text Word]) AND (humans[Filter]) **Translations sports [mh]:** “sports”[MeSH Terms] **Athletic Performance [mh]:** “athletic performance”[MeSH Terms] **baseball [mh]:** “baseball”[MeSH Terms] **basketball [mh]:** “basketball”[MeSH Terms] **bicycling [mh]:** “bicycling”[MeSH Terms] **boxing [mh]:** “boxing”[MeSH Terms] **Boxing [mh]:** “boxing”[MeSH Terms] **cricket sport [mh]:** “cricket sport”[MeSH Terms] **cricket sport [mh]:** “cricket sport”[MeSH Terms] **football [mh]:** “football”[MeSH Terms] **golf [mh]:** “golf”[MeSH Terms] **gymnastics [mh]:** “gymnastics”[MeSH Terms] **hockey [mh]:** “hockey”[MeSH Terms] **martial arts [mh]:** “martial arts”[MeSH Terms] **running [mh]:** “running”[MeSH Terms] **jogging [mh]:** “jogging”[MeSH Terms] **skating [mh]:** “skating”[MeSH Terms] **skiing [mh]:** “skiing”[MeSH Terms] **soccer [mh]:** “soccer”[MeSH Terms] **walking [mh]:** “walking”[MeSH	

	Terms] **swimming [mh]:** "swimming"[MeSH Terms] **wrestling [mh]:** "wrestling"[MeSH Terms]	
#3	**"injury prevention training"[All Fields] OR "strength training activities" [All Fields] OR "neuromuscular training intervention" [All Fields] OR "neuromuscular exercises" [All Fields] OR "stretching"[All Fields] OR "proprioception" [All Fields] OR "conditioning"[All Fields] OR "plyometric activity" [All Fields] OR balance [All Fields] OR "resistance training" [mh] OR "strength training" [tw] OR "weight lifting" [mh] OR sports [mh] OR sport [tw] AND exercise [mh] OR "exercise therapy" [mh] OR exercises [tw] OR "warm-up exercise" [mh] OR "warm- up exercise" [tw] OR cool [All Fields] AND down[All Fields] OR neuromuscular [All Fields] AND "prevention and control" [sh] OR "control groups" [mh] OR control [tw] OR** "Muscle Stretching Exercises"[Mesh] OR "proprioception"[MeSH] OR "plyometric"[All Fields] OR "Circuit-Based Exercise"[Mesh] OR "Postural Balance"[Mesh] OR "core stability"[MeSH] OR core stability[Text Word] OR "Abdominal Core"[Mesh] OR "prevention and control" [Subheading] OR "massage"[MeSH] OR massage[Text Word] OR mobilize[All Fields] OR "risk reduction"[All Fields] OR "manual movement"[All Fields] OR "manual therapy"[All Fields] OR "manual therapies"[Text Word] OR "manual therapy"[Text Word] OR "muskuloskeletal"[All Fields] **Filter: Human** "injury prevention training"[All Fields] OR "strength training activities"[All Fields] OR "neuromuscular training intervention"[All Fields] OR "neuromuscular exercises"[All Fields] OR "stretching"[All Fields] OR "proprioception"[All Fields] OR "conditioning"[All Fields] OR "plyometric activity"[All Fields] OR "stretching"[All Fields] OR "proprioception"[All Fields] OR "conditioning"[All Fields] OR ("balance"[All Fields] OR "balanced"[All Fields] OR "balances"[All Fields] OR "balancing"[All Fields]) OR "resistance training"[MeSH Terms] OR "strength training"[Text Word] OR "weight lifting"[MeSH Terms] OR "sports"[MeSH Terms] OR "sport"[Text Word]) AND "exercise"[MeSH Terms]) OR "exercise therapy"[MeSH Terms] OR "exercises"[Text Word] OR "warm-up exercise"[MeSH Terms] OR "warm-up exercise"[Text Word] OR "cool"[All Fields]) AND "down"[All Fields]) OR "neuromuscular"[All Fields]) AND "prevention and control"[MeSH Subheading]) OR "control groups"[MeSH Terms] OR "control"[Text Word] OR "Muscle Stretching Exercises"[MeSH Terms] OR "proprioception"[MeSH Terms] OR "plyometric"[All Fields] OR "Circuit-Based Exercise"[MeSH Terms] OR "balance"[All Fields] OR "Postural Balance"[MeSH Terms] OR "core stability"[MeSH Terms] OR "core stability"[Text Word] OR "Abdominal Core"[MeSH Terms] OR "prevention and control"[MeSH Subheading] OR "massage"[MeSH Terms] OR "massage"[Text Word] OR ("mobilisation"[All Fields] OR "mobilisations"[All Fields] OR "mobilise"[All Fields] OR "mobilised"[All Fields] OR "mobiliser"[All Fields] OR "mobilisers"[All Fields] OR "mobilises"[All Fields] OR "mobilising"[All Fields] OR "mobilization"[All Fields] OR "mobilizations"[All Fields] OR "mobilize"[All Fields] OR "mobilized"[All Fields] OR "mobilizer"[All Fields] OR "mobilizers"[All Fields] OR "mobilizes"[All Fields] OR "mobilizing"[All Fields]) OR "risk reduction"[All Fields] OR "manual movement"[All Fields] OR "manual therapy"[All Fields] OR "manual therapies"[Text Word] OR "manual therapy"[Text Word] OR "muskuloskeletal"[All Fields]) AND (humans[Filter]) **Translations balance [All Fields]:** "balance"[All Fields] OR "balanced"[All Fields] OR "balances"[All Fields] OR "balancing"[All Fields] **sports [mh]:** "sports"[MeSH Terms]	2,980,524

	exercise [mh]: "exercise"[MeSH Terms] **mobilize[All Fields]:** "mobilisation"[All Fields] OR "mobilisations"[All Fields] OR "mobilise"[All Fields] OR "mobilised"[All Fields] OR "mobiliser"[All Fields] OR "mobilisers"[All Fields] OR "mobilises"[All Fields] OR "mobilising"[All Fields] OR "mobilization"[All Fields] OR "mobilizations"[All Fields] OR "mobilize"[All Fields] OR "mobilized"[All Fields] OR "mobilizer"[All Fields] OR "mobilizers"[All Fields] OR "mobilizes"[All Fields] OR "mobilizing"[All Fields]	
#4	**injured[All Fields] OR injuries[All Fields] OR injuring[All Fields] OR injurious[All Fields] OR injury[All Fields] OR "Wounds and Injuries"[Mesh] OR acute[All Fields] OR Chronic[All Fields] OR Overuse[All Fields]** Filters: **Humans** ("injure"[All Fields] OR "injured"[All Fields] OR "injures"[All Fields] OR "injuring"[All Fields] OR ("injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[MeSH Subheading] OR "injuries"[All Fields] OR "Wounds and Injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "Wounds and Injuries"[All Fields] OR "injurious"[All Fields] OR "injury s"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields]) OR ("injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[MeSH Subheading] OR "injuries"[All Fields] OR "Wounds and Injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "Wounds and Injuries"[All Fields] OR "injurious"[All Fields] OR "injury s"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields]) OR ("injure"[All Fields] OR "injured"[All Fields] OR "injures"[All Fields] OR "injuring"[All Fields]) OR ("injure"[All Fields] OR "injured"[All Fields] OR "injures"[All Fields] OR "injuring"[All Fields]) OR ("injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[MeSH Subheading] OR "injuries"[All Fields] OR "Wounds and Injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "Wounds and Injuries"[All Fields] OR "injurious"[All Fields] OR "injury s"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields]) OR ("injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[MeSH Subheading] OR "injuries"[All Fields] OR "Wounds and Injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "Wounds and Injuries"[All Fields] OR "injurious"[All Fields] OR "injury s"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields]) OR "Wounds and Injuries"[MeSH Terms] OR ("acute"[All Fields] OR "acutely"[All Fields] OR "acutes"[All Fields]) OR ("chronic"[All Fields] OR "chronical"[All Fields] OR "chronically"[All Fields] OR "chronicities"[All Fields] OR "chronicity"[All Fields] OR "chronicization"[All Fields] OR "chronics"[All Fields]) OR ("overuse"[All Fields] OR "overused"[All Fields] OR "overuser"[All Fields] OR "overusers"[All Fields] OR "overuses"[All Fields] OR "overusing"[All Fields])) AND (humans[Filter]) **Translations injured[All Fields]:** "injure"[All Fields] OR "injured"[All Fields] OR "injures"[All Fields] OR "injuring"[All Fields] **injuries[All Fields]:** "injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[Subheading] OR "injuries"[All Fields] OR "wounds and injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "wounds and injuries"[All Fields] OR "injurious"[All Fields] OR "injury's"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields] **injuries[All Fields]:** "injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[Subheading] OR "injuries"[All Fields] OR "wounds and injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "wounds and injuries"[All Fields] OR "injurious"[All Fields] OR	3,335,953

	"injury's"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields] **injuring[All Fields]:** "injure"[All Fields] OR "injured"[All Fields] OR "injures"[All Fields] OR "injuring"[All Fields] **injuring[All Fields]:** "injure"[All Fields] OR "injured"[All Fields] OR "injures"[All Fields] OR "injuring"[All Fields] **injurious[All Fields]:** "injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[Subheading] OR "injuries"[All Fields] OR "wounds and injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "wounds and injuries"[All Fields] OR "injurious"[All Fields] OR "injury's"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields] **injury[All Fields]:** "injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[Subheading] OR "injuries"[All Fields] OR "wounds and injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "wounds and injuries"[All Fields] OR "injurious"[All Fields] OR "injury's"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields] **acute[All Fields]:** "acute"[All Fields] OR "acutely"[All Fields] OR "acutes"[All Fields] **Chronic[All Fields]:** "chronic"[All Fields] OR "chronical"[All Fields] OR "chronically"[All Fields] OR "chronicities"[All Fields] OR "chronicity"[All Fields] OR "chronicization"[All Fields] OR "chronics"[All Fields] **Overuse[All Fields]:** "overuse"[All Fields] OR "overused"[All Fields] OR "overuser"[All Fields] OR "overusers"[All Fields] OR "overuses"[All Fields] OR "overusing"[All Fields]	
#5	**Experimental [All Fields] AND study [All Fields] OR "randomized controlled trial"[Publication Type] OR "randomized controlled trials as topic"[mh] OR "randomized controlled trial"[All Fields] OR "randomized control trial" OR "randomized control trials"[All Fields] OR "randomised control trial"[All Fields] OR "randomised control trials"[All Fields] OR "randomised controlled trial"[All Fields] OR "randomised controlled trials"[All Fields] OR "rct"[All Fields]** Filters: **Humans** (((("experimental"[All Fields] OR "experimentally"[All Fields] OR "experimentals"[All Fields] OR "experimentation"[All Fields] OR "experimentations"[All Fields] OR "experimenter"[All Fields] OR "experimenter s"[All Fields] OR "experimenters"[All Fields]) AND ("studies"[All Fields] OR "study"[All Fields] OR "study s"[All Fields] OR "studying"[All Fields] OR "studys"[All Fields])) OR "randomized controlled trial"[Publication Type] OR "randomized controlled trials as topic"[MeSH Terms] OR "randomized controlled trial"[All Fields] OR "randomized control trial"[All Fields] OR "randomized control trials"[All Fields] OR "randomised control trial"[All Fields] OR "randomised control trials"[All Fields] OR "randomised controlled trial"[All Fields] OR "randomised controlled trials"[All Fields] OR "rct"[All Fields]) AND (humans[Filter])	1,178,202
#6	**#1 AND #2 AND #3 AND #4 AND #5**	770