The effectiveness of exercise interventions to prevent shoulder injuries in sport: A systematic review and meta-analysis

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DECLARATION

I, Johannes Jacobus Wessel Swart, declare that this dissertation contains my own unaided work, except for the assistance stated in the acknowledgements segment. The work was produced under the guidance of my supervisor and with input from a statistician.

Neither the complete dissertation, nor any part thereof has been submitted before for any degree or examination at any other University.

The dissertation is submitted for the Master of Science degree at the University of the Witwatersrand, Johannesburg.

________________ 27/05/2021

Signed Date

PUBLICATIONS AND PRESENTATIONS EMANATING FROM THIS DISSERTATION

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ABSTRACT

Background: The literature supports exercise interventions to avert injuries in the lower extremity as well as injuries in general. Nevertheless, the utilisation of exercise strategies to prevent sports-related shoulder injuries remain unproven. This systematic review's primary aim is to evaluate the effectiveness of exercise interventions to prevent shoulder injuries in athletes.

Aims: Primarily, this review collated and summarised the available evidence on shoulder injury prevention in sport. The first secondary aim is to provide acute versus overuse injury estimates. The second secondary aim is to designate and classify the exercise interventions applied to the upper extremity into strength, flexibility, mobility, plyometrics, proprioception, functional or multimodal exercises. The third secondary aim is to describe and categorise the identified upper extremity components of exercise interventions into open kinematic chain exercises or closed kinematic chain exercises.

Methods: An extensive multi-database search was performed. No language or publication restriction was applied. Twelve databases were searched from inception up until November 2020. The search identified fifteen (15) eligible studies that were included and critically appraised. Data extraction and synthesis followed the Joanna Briggs Institute Reviewer's Manual for Systematic Reviews of Effectiveness and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. The data was synthesised utilising the JBI System for the Unified Management, Assessment and Review of Information to produce several meta-analyses.

Results: The pooled results indicated a statistically significant result with moderate heterogeneity in favour of the application of exercise interventions to prevent shoulder injuries [0.77 (0.65 – 0.91) RR, 95% CI, $P = 0.013$]. An analysis of upper extremity injury shows a smaller effect and with substantial heterogeneity [0.65 (0.56 - 0.77) RR, 95% CI, $P = 0$]. Heterogeneity was fully resolved with the removal of poor methodological studies and reveals a larger statistically significant effect [0.56 (0.38 - 0.82) RR, 95% CI, $P = 0.002$]. Subgroup analysis revealed a slightly greater effect for acute shoulder injuries [0.75 (0.58 – 0.96) RR, 95% CI, $P = 0.024$] compared to overuse injuries [0.75 (0.58 – 0.96) RR, 95% CI, $P = 0.024$]. Shoulder-specific programmes showed a statistically insignificant and inferior effect [0.85 (0.72 - 1.01) RR, 95% CI, $P = 0.067$].

The varieties of exercise interventions applied to the upper extremity consisted of 20% strength, 6% flexibility, 11% mobility, 9% plyometrics, 7% proprioception, 27% functional and 20% multimodal exercises. 56% of shoulder exercises performed was classified as closed kinetic chain exercises.

Conclusion: This systematic review with meta-analysis supports and advocates for the use of exercise interventions to prevent shoulder injuries in sport. The programmes utilised can prevent both acute and overuse shoulder injuries with a slightly greater prophylactic effect in acute injuries. Exercise interventions designed to address the shoulder specifically were not superior to programmes targeting the shoulder incidentally. Future researchers are encouraged to attain higher internal validity levels by reducing biases, improving shoulder specific programmes, and utilising a superiority trial design.

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Research takes place within the community for the greater benefit of society. I extend my sincerest thanks and appreciation to each and every individual participant, although they remain nameless, contributing their time and effort to others' betterment.

A systematic review can only be completed thanks to the labours of other researchers. The end product allows us to peer over our immediate horizon only by virtue of ascension onto the shoulder of giants in an effort to become a foothold for others someday.

Speaking of giants, first and foremost, my profound gratitude to Professor Benita Olivier. Thank you for sharing your endless pool of knowledge, guidance and assistance. Your work ethic leads by example, and your words of encouragement bolstered the resolve.

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Thanks to my parents for providing the opportunities to receive an education, I am forever indebted. For encouraging and emphasising the value of learning, even more so.

To my wife, Marise Swart, for her unwavering and continuous support of my incessant academic endeavours. Your love and caring enabled me to take on these challenges successfully. Forever *amo soltanto te...*

DEDICATION

Dedicated to two remarkable women...

Louwina Marais
(21/12/1935 – 11/08/2019)

and

Katrina van der Merwe
(13/05/1955 - 28/08/2016)

The woods are lovely, dark and deep,
But I have promises to keep,
And miles to go before I sleep,
And miles to go before I sleep."

- Robert Frost "Stopping by Woods on a Snowy Evening"

Source: Collected Poems, Prose, & Plays (Library of America, 1995

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DEFINITION OF TERMS

Closed kinetic chain (CKC): The biomechanical term describing a fixed distal segment of the body or a loaded terminal segment meeting substantial resistance, which does not terminate in free space or moves freely (Karandikar and Vargas, 2011). A push-up is an example of a closed kinetic chain movement for the shoulder joint.

Effectiveness: Studies investigating the extent and context of real-world injury reduction in the population after implementing the intervention into the population's context (Finch et al., 2019, Klugl et al., 2010).

Efficacy: Studies that investigate whether exercise training programmes successfully reduce injuries in a highly controlled setting or ideal setting such as a laboratory setting (Finch et al., 2016, Finch et al., 2019).

Fidelity: The quality of performing the exercises and the extent to which a prescribed programme is followed (Emery and Pasanen, 2019, Hislop et al., 2017).

Incidence: The number of new injury events that were sustained in a specific period within the population investigated (Bahr et al., 2020).

Index injury (illness): The primary or first recorded injury (illness) during the surveillance phase (Raysmith and Drew, 2016).

Neuromuscular training (NMT): Injury prevention programmes with the main aim of improving neuromuscular activation or control (Al Attar and Alshehri, 2019a, Faude et al., 2017).

Open kinetic chain (OKC): The biomechanical term describing a moveable terminal segment of the body that is unloaded and terminates in free space (Karandikar and Vargas, 2011). Movements, such as free-active shoulder flexion, is an example of an open kinetic chain movement.

Prevalence: Denotes the existing number of injuries divided by the whole population at any given point in time (Bahr et al., 2020).

Randomised controlled trials (RCT): Studies where randomisation results in two arms, namely where participants are divided into a control group and a parallel comparison group, which may be either an active (placebo) group or a passive (control) group (McBain et al., 2012b).

Recurrent injury: A secondary or a second recorded injury that occurs in the same location as the index injury (Toohey et al., 2017).

Subsequent injury: A secondary or second recorded injury following the index injury, which differs in location or nature (Toohey et al., 2017).

Surrogate measures: Biomechanical or physiological measurements substituted as intermediary measures of injury incidence rather than the clinical end-point. Studies utilising surrogate injury measures do not prove a reduction of injury incidence but rather the ability to diminish injury risk factors, thereby theoretically decreasing or preventing injuries (McBain et al., 2012a, McBain et al., 2012b). Correcting muscle imbalances or rotator cuff weakness is used as the measure to prove a reduction of shoulder injury rather than recorded injury numbers of the actual incidences.

LIST OF ABBREVIATIONS

Abbreviation	
ACL	Anterior Cruciate Ligament
CI	Confidence Interval
CKC	Closed Kinetic Chain
CONSORT	Consolidated Standards of Reporting Trials
FIFA	Fédération Internationale de Football Association
F-MARC	Fédération Internationale de Football Association Medical and Research Centre
GRADE	Grading of Recommendations, Assessment, Development and Evaluation
ICC	Intraclass Correlation Coefficients
IIR	Injury Incidence Rate
IPP	Injury Prevention Programme
IRR	Injury Rate Ratio
ITT	Intention-to-treat analysis
JBI	Joanna Briggs Institute
MeSH	Medical Subject Headings
NMT	Neuromuscular Training
OKC	Open Kinetic Chain
OR	Odds Ratio
OSTRC	Oslo Sports Trauma Research Centre
PICO	Population Problem, Intervention, Comparison or Control, and Outcome
PP	Per-Protocol (Per-treated) analysis
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	Prospective Register of Systematic Reviews
RCT	Randomised Clinical/Controlled Trials
RE-AIM	Reach, Effectiveness, Adoption, Implementation, and Maintenance
rr	risk ratio
RR	Relative Risk

TRIPP	Translating Research into Injury Prevention Practice Framework
SAFA	South African Football Association
SARU	South African Rugby Union
SPIRIT	Standard Protocol Items: Recommendations for Interventional Trials
SUMARI	System for the Unified Management, Assessment and Review of Information
WHO	World Health Organisation

LIST OF APPENDICES

CHAPTER 1 - INTRODUCTION

1.1 Background

Physical activity is an inherent component of exercise and a foundational requirement for sports participation. Mortality is reduced, and general wellbeing is augmented by the regular performance of exercise (Khan et al., 2012). Members of society enjoy the positive health benefits of physical activity throughout their lifespan; arguably one of the greatest tangible detriments to an active individual's health is when injury strikes (Emery and Pasanen, 2019). Notwithstanding the scientific and technological improvements in injury prevention, musculoskeletal injury in sport remains frequent and widespread with substantial costs to individuals, communities, and society (Emery and Pasanen, 2019, Finch et al., 2019).

Conventional injury surveillance data indicates a higher proportion of injuries to the lower extremity than any other body region. The higher reported prevalence resulted in an absolute emphasis on lower extremity injury prevention research (Cools et al., 2020, McBain et al., 2012a, McBain et al., 2012b, Vriend et al., 2017). The prominence led to three decades of training efficacy studies devised and designed to lessen lower extremity injuries in general or specific anatomical areas of the lower extremity (Emery and Pasanen, 2019, Finch et al., 2019). This approach has shaped the development of the dominant theories in this field.

Hootman et al. (2007), in their widely cited study, strongly recommended a lower extremity research focus based on their collected data from a utilitarian standpoint. More than half of the injuries were to the lower extremity, compared to a quarter that were to the upper extremity in a selection of team sports. In their study, few overhead or throwing sports were monitored, which resulted in a low prevalence rate reported for upper extremity injury. The most concerning aspect of modern injury prevention is despite efforts to reduce injury incidence, injury surveillance studies indicate a general escalation in injuries (Cools et al., 2020).

Injury monitoring has diverged from popular adult team sports into more diverse populations. A comparison of adult athletes *versus* adolescent athletes revealed that the upper extremity and specifically the shoulder, is one of the top five areas sustaining serious injury triggering prolonged training restrictions (Emery et al., 2006). Illustrating that ignoring small *caveats* like severity and burden contributed to assumptions that have diverted the course of research into particular pigeonholes. Asker et al. (2018) encourage primary shoulder prevention intervention, if only to reduce the associated injury burden.

The rate of upper extremity injury is decidedly contingent on the type of sport surveyed. Shoulder injury incidence can range from 18% to 61% in overhead sports where high loads require rapid application and dispersion of forces (Asker et al., 2018, Cools et al., 2015). Repetitive movements inherent to certain sports increase the occurrence of a shoulder injury, as 91% of elite swimmers sustain shoulder injuries due to chronically high workloads (Struyf et al., 2017). Shoulder dysfunction secondary to an injury can severely debilitate and handicap an athlete, resulting in a subsequent reduction in training and performance quality.

Persistently elevated shoulder loads can lead to tissue stress and subsequent injury. The mechanisms that cause injury can range from excessive recurring, rotational patterns found in rowing or swimming, to explosive plyometric shoulder actions intrinsic to throwing sports (Cools et al., 2020). The shoulder is the most vulnerable anatomical area in professional baseball, where pitchers sustain an injury to the area 77% of the time (Fares et al., 2020), and the second most common injury site in weightlifters and powerlifters (Aasa et al., 2017). Acute shoulder injuries are largely well-documented, but the total number of injuries is likely underreported as are those in the lower extremity (Toohey et al., 2017).

A key issue contributing to shoulder injuries' understatement is the large proportion of overuse injuries which are seldom sufficiently detected by injury surveillance programmes. Shoulder injuries are a frequent occurrence in triathlon athletes, who have a three times greater overuse injury incidence than acute injury (Schorn et al., 2018), similarly demonstrating another assumption that leads researchers to concentrate on interventions for acute injuries, as they are simpler to evaluate and monitor than overuse injuries (Brunner et al., 2019).

Specific team sports have a reputation and expectation of low shoulder injury prevalence, such as the lower extremity dominant game of football. On the other hand, football has a 4.6 times higher incidence of shoulder injuries in goalkeepers when compared to field players. The disproportionate ratio alone provides a public health duty to at least examine shoulder injury prevention more thoroughly, despite a low prevalence in football overall (Goodman et al., 2018). Attesting that evidence-based interventions are based on the best data available at the time but are highly dependent on the current direction of research trends.

The aforementioned evidence persuasively corroborates the premise that lower extremity injuries' prevalence exceeds that of the upper extremity in many popular team sports, which arguably may support and substantiate the disproportionate quantity of evidence accrued to lower extremity injury prevention. The argument is further bolstered by researchers advocating for a more significant impact on public health by intervening in the area of maximum incidence, severity, and burden (Emery et al., 2015b).

Nevertheless, this standpoint proves unjustifiable when intensely examining where the majority of research attention is focused. The considerable amount of research devoted to preventing rare and anatomical specific injuries such as an anterior cruciate ligament (ACL) injury in the knee, is a prime example (Huang et al., 2020). An ACL injury is relatively uncommon, with a prevalence of approximately 3-3.5% of all injuries sustained (Hootman et al., 2007, Lewis et al., 2018). One out of 80 athletes will sustain an ACL injury from a high-risk sport (Petushek et al., 2019). Although not wholly without merit because of the severe injury burden, the intense research emphasis seems to lack justification based on prevalence.

The upper extremity, and particularly the shoulder deserves greater attention from the research and sports injury community based on current literature recommendations. The pre-eminence of ACL prevention research may, in part, be due to its consistently successful outcomes and return on resource investment (Huang et al., 2020). In light of the above, the limited research resources spent on shoulder injury prevention seem unjustified. The importance of upper extremity injury prevention is gaining prominence. There is a definite need for a specific review of the available evidence on shoulder injury prevention to provide much-needed lucidity.

The fall-out from sustaining injury spills over into many more facets of athletes' lives than their current health and future co-morbidities. The impact produces psychological, performance and financial obstacles that demand intervention and management over several seasons. Raysmith and Drew (2016) discovered that an average of two weeks are lost per injury in adult track and field athletes, while Emery et al. (2015b) found more than a week's training is lost in youth athletes. Athletes who modify more than 20% of their training due to injury fail to achieve 65% of their performance goals in the season (Raysmith and Drew, 2016).

Contemporary custom encourages upper extremity warm-ups in sports before participation, partly due to the belief that it can reduce injuries. In contrast to the lower extremity's proven effectiveness, the practice is still unsubstantiated (McCrary et al., 2015). Other primary prevention strategies developed from available research recommend equipment adaptations, training interventions, and policy changes to reduce sports injuries in vulnerable groups (Emery et al., 2015b, Emery and Pasanen, 2019, Huang et al., 2020, Klugl et al., 2010, Rossler et al., 2014).

The current prevention guidelines were established from a disproportionate and asymmetrical lower extremity evidence base that neglected the upper extremity unique characteristics and open kinetic chain (OKC) nature. The recommendations are defended continuously by appealing to numerous lower extremity studies' successful outcomes, the greater good or from a deontological imperative. Nonetheless, existing principles are ill-suited and incongruous with upper extremity injury prevention, necessitating a more precise and meticulous investigation into solutions for the critical issues associated with shoulder injuries and prevention (Asker et al., 2018, Cools et al., 2020).

An initial search of the Cochrane Library (Wiley), JBI Evidence Synthesis, MEDLINE (Ovid), and PROSPERO revealed no systematic review investigating the effectiveness of exercise interventions to reduce shoulder injuries in sport. Various systematic reviews have proven exercise intervention effective for all injuries in general, and lower extremity injuries in particular.

However, none has included sufficient upper extremity data to make any evidence-based assertion to its effectiveness (Asker et al., 2018, Brunner et al., 2019, Dijksma et al., 2020, Emery et al., 2015b, Faude et al., 2017, Huang et al., 2020, Lauersen et al., 2014, Lauersen et al., 2018, Leppanen et al., 2014, Rossler et al., 2014, Rossler et al., 2018). Additional evidence is required to endorse the generalisability of exercise effectiveness to reduce shoulder injuries inferred by the majority of studies evaluating general and specifically lower extremity injuries.

The shoulder was explicitly investigated in a systematic review by Asker et al. (2018). The review investigated the risk factors for shoulder injury prevention in overhead sports. The study delimited the inclusion population to overhead athletes. The primary aim of the review was to identify and categorise the risk factors for sustaining shoulder injuries. The secondary objective was to synthesise evidence relevant to shoulder injury prevention in overhead athletes. One relevant study matched the inclusion criteria for prevention and made the synthesis or production of a meta-analysis unfeasible (Andersson et al., 2017). Asker et al. (2018) found shoulder specific investigation extremely limited and excluded studies that recorded incidental shoulder data.

Several randomised controlled trials (RCTs) examining or surveying shoulder injuries have been published since the Asker et al. (2018) review. Sports like baseball (Sakata et al., 2018, Sakata et al., 2019), cricket pace bowlers (Forrest et al., 2020), football (Al Attar et al., 2017, Al Attar and Alshehri, 2019a), handball (Fredriksen et al., 2020, Sommervold and Osteras, 2017), tennis (Pas et al., 2020), and volleyball (Gouttebarge et al., 2020) have published potentially collatable studies. Appropriate studies that rarely fall into the limited scope for overhead athletes and sports should be included, as in Australian football (Finch et al., 2016) and rugby (Attwood et al., 2017).

Eminent reviews purport resistance training to be superior to all other components of injury prevention programmes (IPPs) but may only be applicable to lower extremity injuries and general injury (Brunner et al., 2019, Dijksma et al., 2020, Finch et al., 2019, Lauersen et al., 2018). The literature on whether exercise interventions can reduce shoulder injuries, and whether a specific element in an IPP can produce a superior effect, is currently unclear. Research extrapolation has substituted a specific investigation into shoulder injury prevention. Several studies report divergent findings when injury prevention interventions are applied, compounding the ambiguity and uncertainty (Cools et al., 2020).

Principally, this review will collate and summarise the available evidence on shoulder injury prevention in sport. The study's secondary aims include providing, where possible, acute *versus* overuse estimates. A further aim is, to designate and classify the varieties of exercise interventions applied to the upper extremity by implementing IPPs, into strength, flexibility, mobility, plyometrics, proprioception, functional or multimodal exercises. Ultimately, providing an overview of the components included in modern IPPs implemented for the shoulder.

Lastly, this review will describe and categorise the identified upper extremity components of IPPs into open kinematic chain exercises or closed kinematic chain exercises. According to the author’s knowledge, no meta-analysis investigating the effectiveness of exercise interventions to prevent shoulder injury has been published. A meta-analysis will provide newfound and thought-provoking data, thus advancing knowledge and recommendations for future research in the field.

Prevention is the epitome of successful medical management of sports injuries (Emery and Pasanen, 2019, Hubscher et al., 2010). The dreaded future sequelae subsequent to injury that both athletes and health care practitioners push to the back of their mind until the inevitable concomitant co-morbidities take hold, become nullified if prevented. Primary intervention strategies remain a public health duty which deserves a never-ending search for effectiveness and superiority. From our current panoptic outlook to prevent injuries, the question must be asked: Have the idiosyncrasies in shoulder injury prevention gone unnoticed?

1.2 Research Problem

The strong drive for prevention is warranted as the incidence of sports injury is described as excessive in vulnerable groups like adolescents and youths (Emery et al., 2006). The elevated prevalence of upper extremity injury in overhead sports has forced medical professionals into secondary prevention strategies to permit athletes to train and compete with shoulder problems (Cools et al., 2020). Upper extremity problems have shown a recent surge in awareness from the research community.

Handball athletes frequently practice and contend despite a consistently low shoulder pain level in their dominant arm (Sommervold and Osteras, 2017). As the kinetic chain breaks down due to pain and dysfunction, injuries occur but are frequently ignored until they become severe, resulting in extensive time loss from training and competition. Athletes with less than two injuries or illness bouts per season increase their odds of reaching their set performance goals by three times (Raysmith and Drew, 2016).

Exercise intervention’s effectiveness in preventing general and lower extremity sporting injuries has been well established, including which components are responsible for the lower extremity's most significant result (Finch et al., 2019, Lauersen et al., 2014, Lauersen et al., 2018). Nevertheless, there is a literature gap regarding the effectiveness of exercise interventions to prevent upper extremity injuries and, specifically, shoulder injuries despite some published data available (Asker et al., 2018, Cools et al., 2020, McBain et al., 2012a).

The current focus of injury prevention research is either on preventing acute lower extremity injuries or acute injuries in general (Vriend et al., 2017). The majority (92.1%) of surrogate injury prevention studies focused on the lower extremity, with few studies focusing on either overuse injuries or upper extremity injuries (McBain et al., 2012b). In injury prevention trials assessing effectiveness, the bulk (68.8%) of studies was devoted to the lower extremity, and none specifically addressed the upper extremity (McBain et al., 2012a).

The literature provides recommendations primarily gathered and collated from lower extremity investigations, which functions in a weight-bearing closed kinematic chain and insinuates that it is applicable in a non-weight-bearing OKC of the upper extremity. Aside from the extrapolated findings that infer a causal relationship, limited research exists on the type of components shoulder exercise prevention protocols consist of and their role in effectively preventing acute, overuse, or subsequent injury.

If prevention of at least some injuries is possible, as well as their subsequent detrimental effects, should the investigation of preventive strategies including IPPs not supersede pharmacological or surgical intervention? Precluding concomitant injury that develops as the sequela of the index injury, averts an exponential increase in long-term disability accompanied by ballooning medical costs. At worst, even if primary prevention fails, it can become the basis for secondary prevention intervention.

The gaps found in the newly designated field of sports injury prevention should be considered within context, as this academic speciality only emerged within this century and has only in the last decade started to show more rigorous academic methodology (Emery and Pasanen, 2019, Hootman et al., 2007, Khan et al., 2012). The field is primed to investigate the effectiveness of exercise intervention in the upper extremity and the shoulder specifically. The consistent recommendation for future research from numerous studies for upper extremity synthesis cannot be ignored *ad infinitum*; there is a duty and responsibility to close this *lacuna* in upper extremity injury prevention.

1.3 Systematic review question

Review question: What is the effectiveness of exercise interventions *versus* no intervention or alternative intervention to prevent shoulder injuries in athletes?

1.4 Aims of the systematic review

The primary aim is to find, identify, review, summarise, and synthesise all existing literature on whether exercise interventions can prevent shoulder injuries in athletes from studies that specifically or incidentally investigated the shoulder and upper extremity.

The secondary aims of this study are to:

- Collate acute *versus* overuse data on shoulder injuries and perform an analysis to provide estimates, where feasible.
- Designate and classify the varieties of exercise interventions affecting the upper extremity included in the injury IPPs, into strength, flexibility, mobility, plyometrics, proprioception, functional or multimodal exercises.
- Describe and categorise the components of the IPP's shoulder specific exercises into a closed or open kinematic chain, and establish an overview of current prevention programmes performed in research for the sporting shoulder.

1.5 Significance of the study

This systematic review's findings can substantiate the claim that exercise intervention effectively prevents sports injury to the shoulder. The IPPs' component will be categorised and described, providing an overview of what constitutes current clinical practice. The ability to prevent acute and overuse shoulder injury can supplement the existing amassed literature on extrinsic risk factor reduction for shoulder injuries sustained during sports participation.

The findings can contribute to the contemporary South African sports practice and physical education curricula by enhancing warm-up protocols or supplementary sessions in at-risk groups. The review can increase the awareness of shoulder IPPs and provide estimates on the expected effects of performing these programmes.

Implementation of the findings will conform to South Africa's primary prevention strategy to healthcare and contribute to injury prevention within a local context. Reducing adverse incidents and modifying risk factors is a public health duty required to manage and prevent injuries.

1.6 The framework for the dissertation

The dissertation comprises of six chapters that commence with the introduction of the effectiveness of exercise interventions to prevent shoulder injuries, examining the current evidence on the topic, stating the methodology, presenting the findings of the systematic review and meta-analyses, discussing the findings in light of the existing literature, and concluding with a summary. The summary includes recommendations for clinical practice and future research. The framework of the dissertation is provided in Figure 1.1 below.

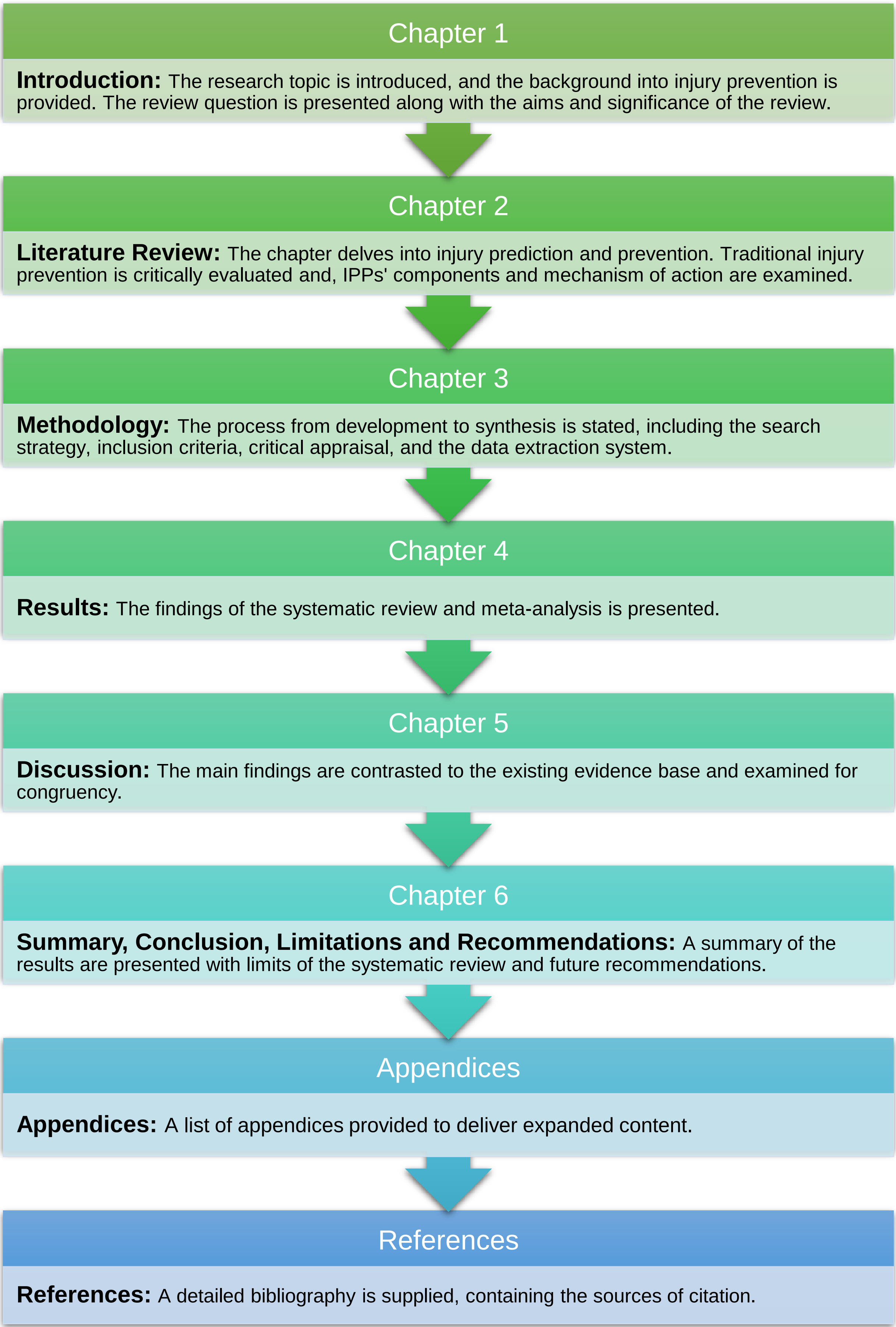


Figure 1.1: Flow diagram of the dissertation

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

The World Health Organisation's (WHO) most recent physical activity guidelines advocate that adults perform 150 to 300 minutes of moderate or 75 to 150 minutes of intense aerobic activity weekly, while youths should aim for 60 minutes of aerobic activity daily (Bull et al., 2020). The endorsements included the newly announced recommendation that all ages should engage in regular strength training to improve health and wellbeing. Physical inactivity globally accelerates chronic disease, premature death, and early disability (Leppanen et al., 2014, Mugele et al., 2018, Rossler et al., 2014). Sports participation is a substantial portion of the daily physical activity quota for both youth and adult athletes.

Participation in sports is fundamental to the maintenance and improvement of an individual's health. Sport participation is a pragmatic primary prevention strategy on a population level that can reduce mortality by 20% to 40%; however, the injuries sustained during training or competition place a massive burden on the individual, society and the health care system (Emery and Pasanen, 2019, Finch et al., 2019, Khan et al., 2012). Sport is the primary cause of injury in children and adolescents, and if prevented enables the enhancement of future welfare and quality of life (Emery et al., 2015b, Faude et al., 2017, Rossler et al., 2014, Rossler et al., 2018).

Sustaining an injury is a common adverse effect of engaging in physical activity and exercise. Exercise is a double-edged sword; it is a public health duty to investigate injury prevention from all possible angles in order to allow society to wield it safely. IPPs are the foundation of the scientific and medical communities' response to the challenge and is the intervention of choice to manage injury risk and incidence (Al Attar and Alshehri, 2019a, Mugele et al., 2018). IPPs may hold the key to reducing the burden of injury in the future.

The background presented above initiates a positive call to action for health professional and researchers alike. The impact and burden of injury are blatantly obvious, the effect of IPPs intervention is justifiably proven, and consistent outcomes seem not just possible but probable with applied effort. The situation in practice is unfortunately not so simple as efficacy does not equate effectiveness in outcomes.

This introduction sequence is nevertheless precisely what Bekker and Clark (2016) have labelled mechanical to the ultimate, and is found consistently in the formulaic approaches or introductions to injury prevention research.

Despite all the single-minded efforts to reduce injuries with exercise interventions, the field continues to dissatisfy and dishearten researchers and athletes with erratic and unpredictable outcomes. Vriend et al. (2017) found that the evidence base for non-exercise interventions was significantly sounder and more robust than exercise interventions. Injury prevention research implementing IPPs has not lived up to the panacea it was touted to be and can deliver inconsistent and undesirable outcomes (Cools et al., 2020, Hulme and Finch, 2015, Klugl et al., 2010, Leppanen et al., 2014).

A myriad of obstacles renders injury prevention problematical, with the failure to accurately predict injuries undoubtedly a forerunner. The traditional injury prevention paradigm promotes the systematic collapse of complex socio-ecological factors into simple individual-level factors, enabling analysis using a biomedical or biomechanical perspective (Bittencourt et al., 2016, Hulme and Finch, 2015). Thus a ‘stiff’ quadricep resulted in a muscle strain without considering the effects of the long bus ride (fatigue), the recent loss of a family member (mental state), absent coach (team communication), or competing in a neighbouring country (unfamiliar track) have in the equation.

This chapter presents a literature review examining injury prevention research with an emphasis on upper extremity injury. The evidence surrounding injuries and their divergent classifications are scrutinised with a delve into the popular upper extremity *versus* lower extremity injury split. The conundrum of injury prediction is assessed, and an overview of injury prevention philosophies is provided. IPPs, their components and mechanisms of action are investigated. The information presented is vital in understanding how injury prevention research is executed and how each aspect influences the reported outcomes.

2.2 Search Strategy for literature review

The first step of the three-step sequential strategy was to explore and discover relevant evidence. A restricted investigative search in MEDLINE (PubMed) was performed using the keywords “shoulder injury”, “primary prevention”, and “exercise intervention”. The initial search developed the outline and framework used to expand the inquiry further into the subject matter. Additional keywords were spawned from the preliminary search results and form the foundation of the targeted search strategy.

The second step was the performance of an expanded search for full-text journal articles published in English. The literature was identified by internet searches of five electronic databases and the google scholar search engine. Consultation of Cochrane Central Register of Controlled Trials in the Cochrane Library (Wiley), MEDLINE (PubMed), Pedro, SPORTdiscus with full text (EBSCOhost), and Web of Sciences (Clarivate Analytics) took place from inception until September 2020. Supplementary searches included “upper extremity injuries”, “injury prediction”, “injury prevention programmes”, and “neuromuscular training” as keywords.

The last step included consulting MEDLINE (PubMed) ’s similar article utility which reveals relevant articles for perusal on the same topic. Backward citation tracking was implemented by manually screening the references of pertinent articles and systematic reviews. Forward citation tracking was implemented on crucial or notable articles utilising the Web of Sciences (Clarivate Analytics) functionality.

2.3 Injuries

2.3.1 Defining injury

Injury is described as the tissue’s physiological failure to rebound or recover after applying acute or accumulative stress and load past its capacity (McBain et al., 2012b, Nielsen et al., 2020b). The first obstacle faced by investigators when formulating a robust injury prevention trial is the conundrum of how to formulate an operational definition for an injury. The definitions tend to be pragmatic to facilitate the ease in injury documentation instead of adhering to a theoretical framework (Fuller et al., 2007), resulting in very context-specific definitions designed for current workability over re-usability.

The definition of injury can be either expansive or narrow, depending on what types of injuries the study is designed to measure, detect, and report (Nielsen et al., 2020b). The literature contains considerable variation in injury definitions which are generally devised around a set of conventional notions. Hootman et al. (2007) stipulated three of these norms rather than a strict criterion to facilitate definition creation for injury surveillance programmes in different sports. Firstly, the injury must be incurred as a direct cause of participation or training. Secondly, the injury should require medical attention. Lastly, the injury restrains competition or training for at least one day. This benchmark is traditionally the departure point in creating a definition for injury, but tends to exclude certain types of injuries as it seems calibrated to target a subset of injuries.

The divergent definitions and the challenges to standardise them have been intensely debated. Emery et al. (2015a) advocate operational descriptions which are succinct and precise based on a minor modification of consensus statements' definitions. The approach permits each researcher individualisation tailored to each study; however, ultimately resulting in similar but not comparable data. Collating and synthesising studies have proved difficult as definitions overlap, making interstudy comparison exceedingly challenging. The dissimilarity of definitions results in problematic injury prevalence and incidence reporting. The issue is not only on sporting code level as found in football but also in specific injury level, such as shoulder injuries (Asker et al., 2018).

A second alternative solution is preferred by the research community, which is establishing a consensus definition specific to the sports code such as football (Fuller et al., 2006) or rugby (Fuller et al., 2007). Others have supported a consensus definition on an organisational level as endorsed by the International Olympic Committee (Bahr et al., 2020), indicating disapproval of adaptation on an individual study level. An organisational definition provides a standardised template for studies investigating the specific sporting codes that form part of the organisation. The researchers must now adapt the research question to the proposed organisational definition rather than the other way around.

The vision of consensus definitions proves popular with researchers in specific sport codes as the definitions are specific enough, whereas the definitions on an organisational level can be overly comprehensive. The other concern is that under-investigated types of injuries will continue to be excluded, as the organisational definitions overlooked them in the first place. The recent efforts to develop an internationally recognised universal consensus statement have remained unsuccessful (Nielsen et al., 2020b). Thus, in practice, a researcher will select the largest organisation's definition; and if inappropriate, the newest sports consensus statement's definition. Lastly, if none is found suitable, the researcher will customise and adapt. All the approaches will be purported to be literature-based decisions despite polar opposite approaches.

The formalising and unifying injury definitions have had positive effects beyond the criticism purported against the approaches. The deliberations have improved sport-specific comparison of injury prevention studies in large and popular team sports, like football internationally (Al Attar et al., 2016, Al Attar and Alshehri, 2019a, Owoeye et al., 2020). Despite the increased collaboration, many individual and eclectic sports still lack a departure point as the generalisability is restricted with the available sport-specific injury definitions. Bahr et al. (2020) endeavoured to address this problem on an organisational level by developing their consensus statement to reflect a sports-generic framework instead of a sport-specific injury definition.

The third and most pragmatic solution was proposed by Nielsen et al. (2020b), as they have petitioned the research community to cease the undertaking of creating a universal sports injury definition at all. Arguing that a definition is ultimately unnecessary and bound to contextual factors inherent in each specific sporting environment. Past universal definition attempts have resulted in extensive and longwinded definitions in an effort to become all-encompassing, but even if cumbersome, the universal definitions all seem decidedly similar at the end (Bahr et al., 2020). The collation issue is solved by stating that each study's definition will be accepted and thus circumscribe the requirements for a reportable injury.

Injury prevention research requires identifying injuries to initiate the data collection process, which ultimately aims to pool and summarise the numbers of events during the trial period. Broad definitions improve statistical power as more injuries are logged, but tend to include many inconsequential or insignificant injuries (Nielsen et al., 2020b). Larger sample sizes are necessary if the injury definition is narrowly defined, as fewer but more targeted injuries are recorded (Fuller et al., 2006). Justifying the position that the injury definition should align with the research question and objectives instead of adhering to prescribed dogma.

Once an adverse event is classified as a recordable injury, various subclassification is performed to improve comparability. Index injuries or first-time injuries are the primary or first recorded injury (illness) during the surveillance phase (McBain et al., 2012b, Raysmith and Drew, 2016). Injuries can further be classified as medical attention injuries when professional medical intervention is sought, or time-loss injuries when athletes cannot train or participate in matches (Fuller et al., 2006, Fuller et al., 2007, Nielsen et al., 2020b). The supplementary classification of injury, including the mode of onset, is desired for robust research (Bahr et al., 2020, Nielsen et al., 2020b).

2.3.2 Mode of onset

The disease model's mode of onset is mainly separated into two categories, namely acute and chronic. Injury prevention research traditionally divides onset into sudden *versus* gradual (Bahr et al., 2020). Sudden onset and acute injury have been used interchangeably, while overuse injury is preferred to chronic and is of gradual onset. Overuse injuries can occur suddenly or gradually, depending on the stress applied to the relevant tissue (Clarsen et al., 2015). Fuller et al. (2006) define an overuse injury as repetitive micro-trauma over multiple events instead of a singular traumatic event that produces acute injuries.

Researchers have not shown much interest in studying overuse injuries in the past and have preferred investigating acute injuries (McBain et al., 2012a). Injury data recording is rarely contemporaneous with the injury, and lacking additional information or an accompanying medical opinion, researchers struggle to classify the mode of onset. Insufficient data prevents any general conclusions on prevention strategies' ability to prevent overuse injuries (Brunner et al., 2019). The methodological difficulties involved in studying overuse injuries is not the only stumbling block. The term is used erratically in the literature, and most studies do not provide clarity on their definition of an overuse injury, making attempts at amalgamation futile (Neil et al., 2018).

Unfortunately, a misunderstanding exists between the mode of onset and the injury mechanism both in the lay and professional sport community. Bahr et al. (2020) classify the mechanism of injury into direct contact, indirect contact and non-contact mechanisms; while Neil et al. (2018), who focused in their study exclusively on explaining injury mechanisms, used it in exactly the opposite manner, as analogous to overuse injuries. From a linguistic perspective, the lexical semantics render the Bahr et al. (2020) interpretation the most compelling.

Regrettably, the disconnect is foreseeable in a field where homogeneity is difficult. It is presumed that a review of the concept should not error in classification. The confusion in published studies is understandable if the perusal of the literature reveals the same incongruity (Bahr et al., 2020, Neil et al., 2018, Nielsen et al., 2020b). The absence of recognising overuse injuries may have little to do with the additional resources required (Clarsen et al., 2015). However, it may partly be due to the ambiguous classification methods, causing researchers to avoid opening up a can of worms.

The research community has acknowledged the deficiency in detecting overuse injury and has redirected their attention to include overuse injuries and illness monitoring (Bahr et al., 2020). Overuse injuries require an inclusive definition and struggle with the notion of capturing injuries directly or indirectly related to the sport, as activities of daily living may result in unwarranted overuse injuries recorded (Nielsen et al., 2020b). Schorn et al. (2018) attempted to simplify their classification to assist triathlon athletes in correctly self-identifying their mode of onset by defining acute injuries as a single sudden traumatic event. Overuse injuries result from elevated volumes of frequent movements and loading. This division still seems to require clinical judgement.

Differentiating between acute and overuse injuries is vital as there is a wide variation in the prevalence and triggering mechanisms. Acute injuries comprised 95% of overall injuries, with direct contact as the most common mechanism in college football (Goodman et al., 2018). In the umbrella review by Brunner et al. (2019), all the included systematic reviews concentrated predominantly on acute injuries, leaving insufficient data to generate a conclusion on overuse injuries. Limited evidence exists for non-contact sports or overuse injuries overall (Klugl et al., 2010, McBain et al., 2012a).

The relative paucity of evidence on the effectiveness or efficacy of exercise interventions to prevent overuse injuries or shoulder injuries is manifest (McBain et al., 2012b). Few have underscored the impact of overuse shoulder injuries. Limited evidence provides some insight, as weightlifting studies report a prevalence of 25% to 40% overuse injuries, of which 93% remained long-term (Aasa et al., 2017). Schorn et al. (2018) reported that male triathletes sustain more acute injuries than female triathletes (8% versus 2%), indicating possible sex differences. Overuse injuries for triathletes were linked to more races competed, indicating higher risk with increased participation. The regular use of paddles as a training aid in swimming correlated to a 24% increase in risk to sustain an overuse injury.

The complexity is compounded further when determining the mode of onset of a secondary injury. First of all, it should be established if the injury is recurrent or subsequent. A recurrent injury is an injury to the same anatomical site after return to play, while a subsequent injury varies in type and site compared to the index injury (Fuller et al., 2007, McBain et al., 2012b, Toohey et al., 2017). Bahr et al. (2020) further propose that a recurrent injury should be considered a recurrence only if an index injury has healed completely, while an unhealed index injury is deemed an exacerbation. Detecting subsequent injuries is a modern addition to injury surveillance introduced in the latter half of the decade.

Previous, high-quality injury prevention research reported only lower extremity recurrent injury rates and not the causally linked subsequent injuries. Inadequate documentation of subsequent injury has likely resulted in the published injury rates being underreported (Toohey et al., 2017). The added intricacies required to detect subsequent injuries have made researchers reluctant to add the classification to studies. The inclusion of subsequent injuries can meaningfully improve our understanding of epidemiological injury data, but it does regrettably require more knowledgeable human resources.

The research revealed that track and field athletes with multiple injuries during the season are likely suffering re-injuries rather than new injuries (Raysmith and Drew, 2016). These injuries may either be recurrent or subsequent. An example shows that depending on the criteria set out in a study; a calf muscle strain could be classified as an index injury or a subsequent injury based on whether the previous hamstring injury was taken into account. If a history of calf injury exists, it would be regarded as a recurrent injury, but if that injury had not fully recovered, it will be designated an exacerbation of the index injury.

Sub-classification can be confusing for researchers and the sporting community alike. The best practice guidelines state that transparent reporting for multiple sub-classifications is necessary, as well as patently disclosing all assumed definitions in a manuscript (Nielsen et al., 2020b). New technology has been introduced to simplify classification, as Toohey et al. (2018) have developed a new web-based version of the subsequent injury categorisation model (SIC-2.0) that assists electronically with classification. Once the injury type is definitively identified, the injury is recordable. The next step is to allocate the injury to an anatomical area, characteristically the lower extremity or the upper extremity.

2.3.3 Lower extremity injuries

The dominance of lower extremity investigations in injury prevention research has been extensive. McBain et al. (2012b) reported that 92.1% of efficacy trials studied the lower extremity in contact sports, and the most common injuries were to the joints and ligaments. In contrast, 70% of effectiveness trials investigate the lower extremity similarly in contact sports, while the focus remained on joint and ligament injuries (McBain et al., 2012a). For the most part, the research on injury prevention is devoted to investigating the prevention efficacy of interventions in the lower extremity or overall (Emery and Pasanen, 2019, Vriend et al., 2017).

Distinct ideologies in injury prevention for the lower extremity exist and are based on which assumptions are adopted by the researcher regarding contact and non-contact injury prevention. The prevailing narrative is that non-contact injuries are theoretically preventable, while a certain low percentage of contact injuries may potentially be preventable. The discrepancy produced by actual injury recording versus theoretical estimates is explained as deficiencies in intervention, application or performance. The conundrum lies in deciding on the best intervention approach in contact sports to prevent contact injuries or non-contact sports to prevent non-contact injuries.

The assumptions must be juxtaposed against the reported prevalence to provide context for the approach and justify the need for interventions that hypothetically favour non-contact injuries for superior results and contact injuries for maximum effect. Non-contact injuries, although secondary to contact injuries, account for 36.8% of all lower extremity injuries sustained during practice in a variety of college sports (Hootman et al., 2007). In adolescence, the lower extremity injury rate is 54.7%, with non-contact injuries accounting for 55% of that total (Emery et al., 2006). The sizeable potential impact that prevention programmes can make on non-contact injuries is evident from the evidence above.

Unexpectedly, most injuries sustained in soccer are by contact, but prevention programmes nevertheless show substantial and proven effectiveness. The majority of injuries occur as contact injuries to the lower extremity, between 60% to 90% of injuries across all ages and sexes (Owoeye et al., 2020), yet prevention programmes can still prevent 29% of lower extremity injuries (Al Attar and Alshehri, 2019b). According to the prevalence data, it seems highly unlikely that IPPs prevent almost all non-contact injuries as that is the 10% to 40% residual proportion left. It is more reasonable to assume that the prevalence and the incidence data may be inaccurate. Another explanation is that the proportion of contact *versus* non-contact injuries being prevented is uncertain, and the programmes may prevent both but by an unknown ratio.

The large amount of prevalence and incidence data in lower extremity injuries requires careful and diligent recording to enable useful data extraction. Bahr et al. (2020) recommend sub-categorising body areas under the lower extremity for injury surveillance programmes into the hip, groin, thigh, knee, lower leg, ankle, and foot for the best extraction of data. Despite reportedly suffering from the highest injury rates, a potential still exists for underreporting lower extremity injuries. That is hugely concerning considering more than half of the injuries sustained during activity are to the lower extremity (Emery et al., 2006, Emery and Pasanen, 2019, Hootman et al., 2007, Toohey et al., 2017).

The unknown extent of the underreporting further promotes the devotion of research, education and training intervention to just the lower extremity to achieve maximum utility (Hootman et al., 2007). Re-injuries are not consistently monitored, which is partially responsible for the underestimation. A history of a previous lower extremity injury is a decisive determinant of a recurrence of the same injury in an active population (Toohey et al., 2017). Studies regrettably do not typically have access to an athlete's full medical history as even the athlete struggles to recall all the injuries, leaving re-injuries susceptible to recall bias.

Emery et al. (2006) found that adolescents sustain more than half of their most severe injuries as re-injury to previously injured areas, and that 64.3% of all injuries will be severe enough to require medical attention. Athletes are not prone to sustain new injuries before a competition but are liable to suffer a reoccurrence of the same injury in the six months prior (Raysmith and Drew, 2016). The severity of re-injury can be greater than the index injury, making the prevention of re-occurrence another clinical priority. However, implementing prevention strategies to prevent lower extremity re-injury is technically no longer a primary strategy but a secondary prevention strategy.

Prevention programmes regularly blur the lines between primary *versus* secondary prevention, none more so than with subsequent injuries. Toohey et al. (2017) identified several causal relationships between lower extremity injury and subsequent injury. An existing ACL injury resulted in a two-fold increase risk of a hamstring injury. A history of lower extremity muscular injury raises the risk of muscle injury to another anatomical site. A successive hamstring injury was linked to a primary spinal injury. An existing lower extremity joint injury resulted in an increased risk in all other types of injury. Sustaining a concussion drastically compounds the risks and odds of incurring a successive lower extremity musculoskeletal injury.

The aftermath of a lower extremity injury results in amplified multiple-cause morbidity induced by low physical activity levels and the potential development of premature post-traumatic osteoarthritis (Emery et al., 2015a, Emery and Pasanen, 2019, Lewis et al., 2018). The burden of injury is too high for the individual and community in terms of biological, economical and psychological cost (Khan et al., 2012). The prevalence, incidence, mechanism, and consequences of lower extremity injury have been thoroughly investigated to provide substantial certainty. The literature base can now be differentiated against the under-researched upper extremity.

2.3.4 Upper extremity injuries

The lack of literature for upper extremity injuries is conspicuous when contrasted to the lower extremity's evidence base. Monitoring and recording of upper extremity injuries is not a core objective in most studies. Incidental data from lower extremity studies enabled pooling and further investigations when documented in primary studies. Bahr et al. (2020) recommended including the upper extremity as a primary category for injury surveillance programmes but further dividing the anatomical segments into the shoulder, upper arm, elbow, forearm, wrist, and hand. The joint or segment approach allows for standardisation and facilitates individual injury extraction for less researched injuries from the data.

Can the shoulder be a clinical priority if more than half of injuries occur in the lower extremity? A shoulder injury is likely to incapacitate an athlete extensively or result in permanent disability (Asker et al., 2018, Emery et al., 2006). In major league baseball, the prime injury site is the shoulder, affecting the majority of pitchers and resulting in an average of 69 days on the disability list (Fares et al., 2020). The severity and injury burden are commonly extensive with an injury to the shoulder.

The second most injured site in weightlifting and powerlifting is the shoulder with an incidence of 2.4 to 3.3 injuries per 1000 hours and 1.0 to 4.4 injuries per 1000 hours, respectively (Aasa et al., 2017). The shoulder injury incidence in triathlon is between 0.11 to 0.33 per 1000 hours (Schorn et al., 2018). The scale of the problem is substantial even without considering that the underreporting may be larger than that of the lower extremity (Cools et al., 2015, Cools et al., 2020, Toohey et al., 2017).

A causative factor in underestimating the incidence data is the large proportion of overuse injuries that are seldom sufficiently detected by injury surveillance programmes. Overuse shoulder injuries are more prevalent than acute shoulder injuries in triathletes, yet the attention is focused on more easily managed acute injuries (Schorn et al., 2018). Acute injuries may also be underreported, but due to the methodological difficulties in studying overuse injuries, the imprecision rate may be severely underestimated (Brunner et al., 2019). Intensified surveillance efforts are necessary to enhance individual monitoring of sports to improve injury data collection quality, emphasising the detection of overuse injuries.

Traditionally lower extremity dominant sports view upper extremity injuries as a minimal occurrence and consider these a minor inconvenience. Goodman et al. (2018) found 27 upper extremity injuries per 1000 athletic exposures in collegiate football players. In football, male goalkeepers have a 4.6 times higher risk for upper extremity injury than their teammates, while female goalkeepers have double the risk compared to their male counterparts (Al Attar and Alshehri, 2019a, Goodman et al., 2018).

The discrepancy has prompted the Fédération Internationale de Football Association (FIFA) to develop one of the first sport-specific shoulder prevention programmes for football players. The programme is based on the same methodology applied in the FIFA 11+. Bearing in mind that this is the first organisational based intervention programme for the upper extremity and yet the project was initiated in a lower extremity dominant sport.

The 'FIFA 11+ Shoulder' will replace regular warm-up and will focus on core stability, eccentric rotator cuff strength, sensorimotor stimulation, agility, plyometrics and neuromuscular control (Ejnisman et al., 2016). The effectiveness of the FIFA 11+

shows immense promise based on a currently unpublished study (Al Attar and Alshehri, 2019a). Fuller et al. (2007) recommended adaptation of the FIFA football screening for Rugby Union to identify the dominant arm similarly to the dominant foot due to the prominence and high prevalence of shoulder injuries in the dominant extremity. The upper extremity struggles with additional data extraction as the records generality lack the nuances that have become the *lower extremity's status quo*.

One such nuance and a critical difference is the binary nature of lower extremity injury *versus* the continuous character described by upper extremity athletes. Sport induced shoulder pain and injury is a substantial hardship endured recurrently by overhead sports (Cools et al., 2020). Many overhead athletes in sports like handball, volleyball and tennis train and compete despite intermittent or constant shoulder pain (Andersson et al., 2017, Asker et al., 2018, Gouttebarge et al., 2020, Kekelekis et al., 2020). Taking into account that Raysmith and Drew (2016) found that each week in which pain compels an athlete to modify their training results in a 26% decline in the odds of achieving planned performance goals. These handicapped overhead athletes will battle to excel when beset by chronic pain.

The upper extremity athlete's shoulder is either burdened by high severity or continuous low-level handicap with limited middle ground (Andersson et al., 2017, Asker et al., 2018, Emery et al., 2006). Contemplating the unremitting nature, any exacerbation can push tissue stress past being manageable and lead to catastrophic failure. Adult athletes experience an average burden of injury of two weeks per season (Raysmith and Drew, 2016). The indirect cost of injury resulting in loss of time from work, reduced productivity and, loss of quality of life is substantial even if difficulty exists in estimating an exact cost. The consideration should extend to how symptoms less severe but with a higher burden, inherent in the upper extremity, impact the cost.

The literature provides no agreement regarding intrinsic risk factors for acute or overuse shoulder injury. Shoulder range of motion, rotator cuff imbalances, and scapular performance have been identified as factors found in incorrect shoulder biomechanics (Cools et al., 2015). Risk factors identified in tennis are scapular dyskinesia, extended play, muscular fatigue, scapular and thoracic movement, glenohumeral kinematics, and general playing ability (Kekelekis et al., 2020). These intrinsic risk factors are purportedly the largest influence on injury by intervention, like neuromuscular training (NMT).

In contrast, Asker et al. (2018) found that non-modifiable risk factors tend to predominate in shoulder injury incidence. Participation type, sex, player position and history of injury are the main risks for overhead athletes' injuries. These risks are resistant to change through intervention, and cast serious doubt on the continued application of the same research methodology as the lower extremity, where performing efficacy studies dominate. Research preference may be responsible for emphasising modifiable intrinsic risk factors over investigating the non-modifiable factors.

An active society is a prime directive, but all participation should be considered in light of the risk of injury-causing permanent disability (Emery and Pasanen, 2019, Leppanen et al., 2014). In juxtaposition with lower extremity injuries, the upper extremity requires considerable attention to provide adequate evidence for an accurate determination of the prevalence, incidence, mechanism, and consequences. More evidence is needed to determine the extent of the problem and the influence of various factors, including subsequent injuries, will have on the reportable upper extremity injury rates.

2.4 Prediction of injuries

Bahr (2016) emphasises that screening a large group of asymptomatic individuals is essential to identify illnesses or injury risks. The biomedical paradigm's ultimate aim is early detection and diagnosis in a smaller at-risk group to allow for the quick application of care to stop a disease's sequelae. The disease model for screening was directly transposed into the injury aetiology model. The framework differs fundamentally as screenings are not performed to determine if an athlete is injured or not; they are required to predict a future occurrence, whereas disease screening only determines presence (Verhagen et al., 2018).

Screening is performed at a population level and testing takes place on an individual level. Thus teams and athletes get screened and an individual athlete is tested (Steele, 2018). The WHO recommends a critical appraisal of screening programmes to distinguish between potential detriment or benefit to the community if implemented (Wilson and Jungner, 1968). The criteria were developed for diseases and are presented in its original format and modified for injury prevention in Figure 2.1. The screening of athletes has to benefit the community or the individual in order to continue with the practice ethically.

Screening to identify high-risk individuals is proposed to be an indispensable component of injury prevention research and aids in determining where intervention is critical. The prevention paradox confounds this issue by revealing that high-risk individuals sustain fewer injuries than low and moderate-risk individuals (Verhagen et al., 2018). The obvious solution will then be to apply the intervention, irrespective of the individual's risk, weakening the argument to screen for high-risk individuals.

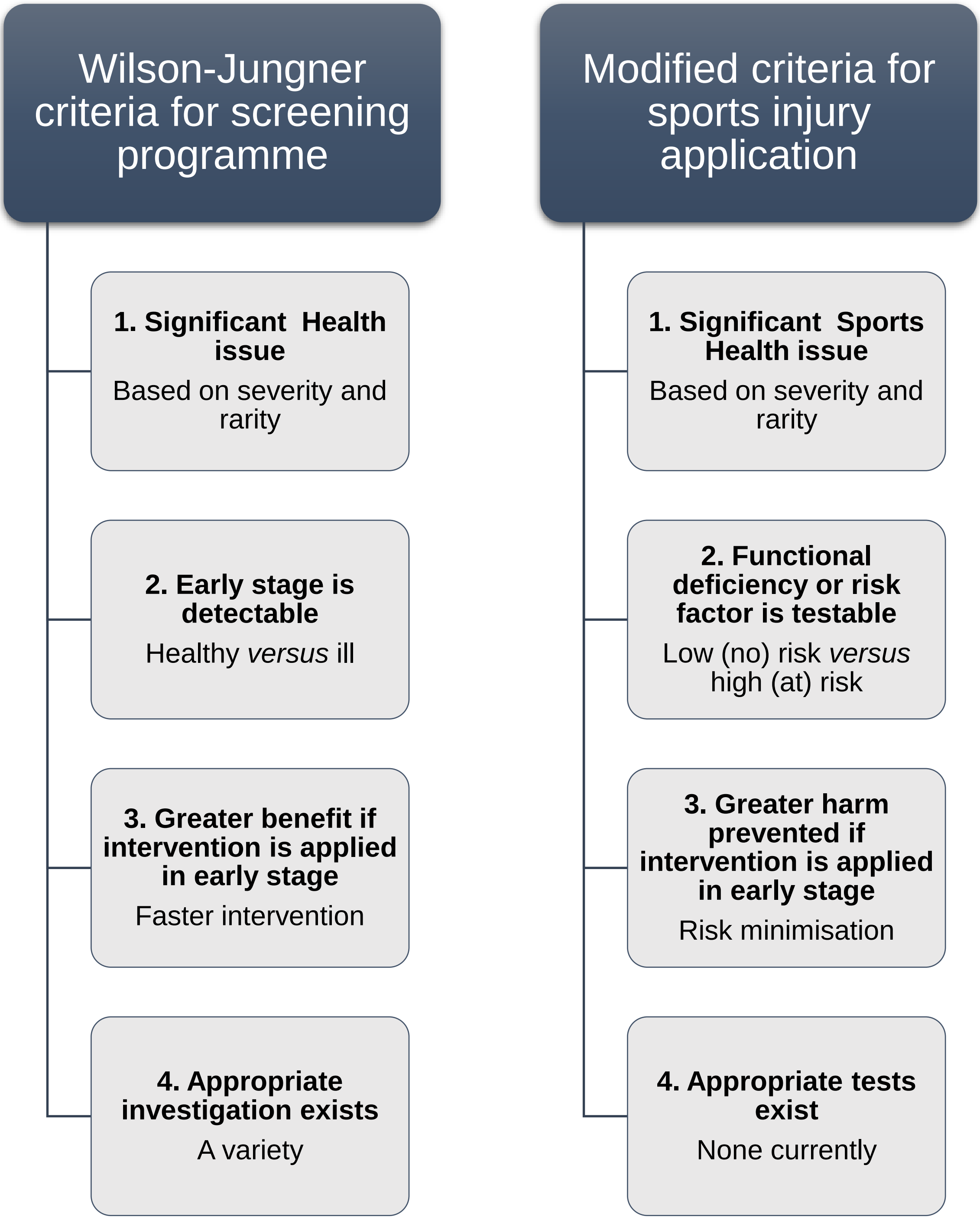


Figure 2.1: Modified Wilson-Jungner Criteria summarised from Wilson and Jungner (1968) and Bahr (2016)

Injury prevention is a critical component of primary care with an immense prospective benefit for an individual's wellbeing. The prevention of the secondary complications that develop post-injury is a call to arms, as the consequences can include early osteoarthritis and a reduction of physical capacity that can lead to disability and premature death (Emery et al., 2015a, Emery and Pasanen, 2019, Klugl et al., 2010). Regrettably, injury prevention is predicated on the imprecise and murky foundation of predictive injury forecasting.

Injury prediction is consistently understood by simplifying components into rudimentary parts and applying reductionism until the forecast is linear; for example, a 'tight hamstring' will result in a hamstring strain (Bittencourt et al., 2016). The central implicit assumption is that the whole will be equal to the sum of its parts (Hulme and Finch, 2015). Unidirectional forecasting theoretically allows the possibility for accurate prediction. However, the scientific community has only had mixed success and acknowledges that identifying simple causal relationships is not sufficient to enable prediction (Bekker and Clark, 2016, Cools et al., 2020).

Linear prediction works sufficiently for an event close to the exposure with few interacting elements (Bittencourt et al., 2016). This proximity aspect makes acute injuries easier to examine than overuse injuries. Analysis might reveal a causal relationship between a risk factor and the adverse event, but it does not necessarily enable prediction (Bahr, 2016). A single causal relationship may not be sufficient, on its own, to trigger an adverse event. Understanding an adverse event in terms of monocausality has been replaced by acknowledging multi-factorialism and complex adaptive systems (Hulme and Finch, 2015).

Training load can serve as an example of how linear prediction can lead to circular reasoning if multiple inputs are ignored. Gabbett (2016) described the injury-training paradox, which is a controversial tenant in injury prediction and prevention. One of the fundamental reasons why exercise and training are performed, is to develop physical capacity and qualities. The development allows greater resilience and training tolerance, which in turn should hypothetically protect against injuries. On the other hand, adding extra training in the form of a prevention programme increases training load, which, according to current conventions, causes a higher rate of injuries (Gabbett, 2020).

Bahr (2016) explains that currently, no screening test exists with sufficient test properties to predict injury, and as of yet, no quantitative research provides validation to any screening for risk of injury. His study, titled 'Why screening tests to predict injury do not work - and probably never will…: a critical review' and the content therein has been controversial since it was first published. He unequivocally implies that screening will never predict injuries. History has proved many wrong for claiming impossibility, merely to have others succeed in the improbable. A shift in paradigm paired with the application of increasingly advanced technology, might solve our current inability to predict injuries.

Although the criticism of Bahr (2016) is valid at this time, it may be excessive as a similar problem exists with the diagnostic accuracy of physical tests in isolation. Physical tests have weak test properties in isolation; it is up to the researcher to identify which battery of physical tests in conjunction with clinical interpretation allows for the highest acceptable test properties (Verhagen et al., 2018). The same problems faced by research examining specific shoulder pathology interventions that use pre- and post-physical tests, plague screening and by extension prediction (Cools et al., 2015, Cools et al., 2020).

The upper extremity has a restricted range of validated functional tests available and is generally dominated by simplistic range of motion tests and basic strength tests, which although reliable, have unknown predictive value (Cools et al., 2015, Cools et al., 2020). The argument that only medically useful and cost-effective screenings should be pursued to limit adverse effects remains a valid argument even in injury prevention (Steele, 2018). The only problem is that the research lacks surety on which tests are or could be useful. Concerns have been raised that harmful effects with screenings cannot be uncovered in the fields which have a history of reluctance to disclose adverse effects (Emery et al., 2015a).

Authors have rallied to support continued screenings and have claimed that the primary aim should be to assess the athlete's present condition (Cools et al., 2020). Baseline testing enables athletes to be measured against themselves and positioned in their teams, providing valuable benchmarks (Verhagen et al., 2018). The shift in validation can enable clinicians to screen legally, ethically and with costs, but it will not further advance prediction. Bittencourt et al. (2012) provide an alternative method to improve prediction by observing stable interactions between risk factors, resulting in evident stable profiles similar to a test battery.

“At a methodological level, complexity assumes that prediction relies on probability and not straightforward causality” (Bittencourt et al., 2016 p. 1313). The answer to improving our predictive capabilities relies on a paradigm shift in clinical thinking. The injury event is predicated on choices, positive actions and interactions between multiple factors across the entire system (Hulme and Finch, 2015). Notwithstanding, the current purported futility of screening tests in injury prevention, screening on an individual level should not be dismissed (Verhagen et al., 2018) as it contributes to building risk profiles. Today, clinicians are better at detecting when injuries were improbable to happen (i.e., true negatives) than predicting injuries (Gabbett, 2016).

At worst, injury prediction is at this time fatally flawed and, at best may become an inexact science. The difficulty does not subtract from the premise that although elimination of all injuries is impossible, the severity and incidence of countless injuries can be reduced (Emery et al., 2015b, Emery and Pasanen, 2019). The literature indicates that injury prevention is feasible and achievable, but accurate predictions are currently unlikely (Bahr, 2016, Cools et al., 2020, Plummer et al., 2019). The research community must change tactics and alter its prevention philosophies to facilitate a breakthrough that would undoubtedly become a watershed moment in the field.

2.5 Injury prevention philosophies

Thorough knowledge of the types of studies designs and their proliferation in the field is required to understand decisions taken in collation and syntheses. The selection of study design can identify different outcomes. The philosophical approaches permeate how the outcomes are investigated and analysed. The approaches underpin the understanding and interpretation of the results in their contexts. Collating studies investigating different sporting codes and various statistical analyses models requires an understanding of the fundamental frameworks in order to critically appraise and judiciously evaluate their findings.

2.5.1 An overview of study designs

McBain et al. (2012b) found that efficacy trials employed RCT designs have multiplied by 650% since 1980. Equipment studies have declined by 35% since the 21st century, while exercise studies increased by 213%. The bulk of studies investigated contact sport (almost 60%), with less than a quarter surveying collision and non-contact sport, respectively. Contact sports include sports where player contact is permissible such as rugby or ice-hockey, while in collision sports like hockey or netball, the contact should be unintentional or else it is a violation of the rules. Study design determines which type of findings can be made, and the constrained emphasis on non-contact sport contributed to the limited investigation into overuse injuries.

In a five year period from 2000, the RCTs investigating injury prevention doubled (Engebretsen and Bahr, 2005). McBain et al. (2012a) performed a systematic review investigating effectiveness trials and discovered that 40% were RCT, while 30% were cohort studies. The emphasis was on studying protective gear (42.1%), training strategies (32.4%), and only the minority consisted of education or rule adaptation. Similarly, almost 40% of the studies were conducted in contact and collision sports, while non-contact sport received limited attention (20%). The largest proportion (70%) of studies investigating all forms of exercise prevention strategies are RCTs (Van Reijen et al., 2017, Vriend et al., 2017).

Klugl et al. (2010) found in their analysis of the published literature that 10% of studies researched efficacy, while less than 1% examined effectiveness. The large number and rapid publication of efficacy studies are understandable as they are simpler to develop and implement and require fewer participants and are relatively inexpensive to initiate. Although the RCT history in injury prevention is relatively recent and is generally accepted as high-quality evidence, it is crucial to collate RCT and synthesise it into meta-analyses to deliver the highest level of evidence (Emery et al., 2015a).

Systematic reviews on the topic are surprisingly abundant, but deficiencies exist in generalisability as meta-analyses are few and far between. The lack of meta-analyses can be attributed to heterogeneity and extracting the same pool of limited studies (Leppanen et al., 2014). Half of the studies in sports injury prevention since 1938 were derivates, while half of the remaining publications constituted non-original research (Klugl et al., 2010). Derivates are reviews, editorials, and comments providing expert opinion on the subject. Considerable overlap of systematic reviews exists in the field, consisting of many of the same primary studies and revealing the over-publication of reviews in the lower extremity (Brunner et al., 2019).

A decade after the publication of a landmark study, it generates a massive spike in similar studies. This decade delay has been identified in injury prevention studies, particularly the effectiveness variety, such as other medical research areas (McBain et al., 2012b). The evolution seems constant, as Hootman et al. (2007) expressed the view that sports medicine was evolving at the time regarding evidence-based interventions and improvement of diagnostic attentiveness. The last decade has finally seen the development of methodically rigorous studies coming to the fore, providing a baseline for a vastly superior standard (Emery and Pasanen, 2019).

2.5.2 The traditional approach

For the past three decades, the four-step Sequence of Prevention model on injury prevention by van Mechelen (1997) has been the cornerstone for creating and evaluating IPPs (Emery and Pasanen, 2019). The model, displayed in Figure 2.2, is predicated on the assumption that prior knowledge of injury incidence (step 1) and injury mechanisms (step 2) is required to develop a preventative programme. The implementation (step 3) is performed based on that prior knowledge, preferably in high-risk groups. Finally, re-assessment (step 4) of the first step is performed to determine whether reduced injury risks or injuries were successfully achieved (Mugele et al., 2018).

The approach is also labelled the simple approach. This linear system assumes a direct causal relationship between injury risk factors and actual injury (Bekker and Clark, 2016, Bittencourt et al., 2012), as well as with the intervention and a reduction in injury. The method was developed under the objective scientific doctrine from a biomedical perspective and primarily constructed to understand pathophysiology; and then translated into sports medicine aetiology (Hulme and Finch, 2015). This system and general approach was yet again inherited from a model designed to address disease primarily.

Bekker and Clark (2016) depict the method as a script-based methodology where the ‘best’ programme is the ultimate goal, and the role of research is to pronounce programme success. In the disease model, the first step is to identify the risk factors for a disease and secondly, the causal mechanism behind the adverse condition (Hulme and Finch, 2015). These steps have been diligently adhered to in injury prevention with a vigorous effort to record injuries and uncover risk factors or injury mechanisms. The approach aligned with the search for causal relationships more than contemplating injury prediction (Bittencourt et al., 2016).

Figure 2.2: Sequence of Prevention model as presented by van Mechelen et al. (1992)

The scientific community agrees that the optimal approach to assess the effectiveness and the efficacy of IPP or screenings is RCTs; as the design is ideal for identifying a causal connection over simple correlation (Emery, 2007, Emery et al., 2015a, Mugele et al., 2018, Steele, 2018, Tufanaru et al., 2015). Previously, a sizable number of studies utilised a cross-over design to examine protective equipment, but recently the shift towards exercise interventions has necessitated an increase in RCTs to test training-related prevention strategies (McBain et al., 2012b).

Entrants into the field recognise that optimal designs for their research are critical. However, their methodology is habitually obsolete, steeped in the traditional approach thinking despite the availability of guidelines like the Consolidated Standards of Reporting Trials (CONSORT) and the Preferred Reporting Items for Systematic review and Meta-analysis (PRISMA) (Liberati et al., 2009, Moher et al., 2015, Moher et al., 2003). As the development of papers for publication often takes a tremendous amount of time, entrants should not rely on published papers for methodology replication. Researchers are responsible to remain up to date with current consensus statements on methodology (Bahr et al., 2020, Clarsen et al., 2020, Nielsen et al., 2020b).

The preparation and guidance of new researchers is insufficient, with new members and veterans alike using statistical systems or methods not configured to their data or ill-suited to answer their research question (Nielsen et al., 2020b). The focus is still on individual-level problems in isolation and within the direct ecosystem in which they operate (Hulme and Finch, 2015), especially when teaching inexperienced researchers. A study designed around the traditional approach might be easier to perform for a novice investigator; however, it must be measured against the value it can contribute to the literature.

Historically, incidence surveillance and risk factor identification were the primary focus of injury prevention research (Finch, 2006, Klugl et al., 2010, Mugele et al., 2018). The bulk of the studies rarely progressed beyond aetiology investigations preventing the research from making a real-world impact and earning the moniker of effectiveness trials (Finch et al., 2019). The lion's share of current clinical practice comes from research into risk factor reduction instead of actual injury reduction, known as efficacy trials (McBain et al., 2012b).

The distribution should come as no surprise as efficacy should predate effectiveness, as is currently the case (Klugl et al., 2010). The ratio of efficacy studies is nevertheless too large, and the promotion of effectiveness studies are required. A real constraint is the inconsistency in which risk factors are identified for the same injury phenomenon (Bittencourt et al., 2016), meaning that from a linear model, efficacy studies probably did not sequentially build-up an evidence base. Thus, the efficacy studies' reliability appears to be low, as replicating the same study can result in different outcomes.

Acknowledging the fact that all efficacy trials will not collate with precision, the extent of the problem and the consequences of too many diverse efficacy studies require investigation. The directive to fully map the first two steps (injury incidence and mechanisms) before continuing with effectiveness studies is unfeasible. The evidence base cannot provide clinically relevant findings to policymakers unless the effectiveness of preventing adverse events and risk factors is investigated. The sporting community has indicated the need for more diverse information on injury prevention.

Contemporary calls for comprehensive economic assessment to determine the financial cost of injury and the potential cost savings by preventative programmes has come to the fore (Emery and Pasanen, 2019). Implementing prophylactic training in an ACL injury high-risk population between the ages of 12 to 25 years can result in a decreased cost of $693 (US) per person or a total saving of $221 870 880 (US) to a health care system (Lewis et al., 2018).

The criticism levelled at the traditional research approach provides valuable insight into how other perspectives have improved and altered designs to improve accuracy and precision results. The first main criticism detailed by Emery and Pasanen (2019) has highlighted that RCTs are not always possible or practical in the research into injury prevention. Their results restricts interpretation and extrapolation while excluding less meticulous study designs like non-randomised cohort designs typically found in rule adaptation research (Vriend et al., 2017). The reductive application of RCT explains the challenging search to determine causality as they are designed to fail to recognise inherent non-linearity (Bittencourt et al., 2016).

Secondly, Hootman et al. (2007) implore researchers to shift their focus to approaches that apply to general injury prevention instead of a minority-focused isolated joint or site in the lower extremity. Minority approaches go hand in hand with researchers investigating a single risk factor in one sporting code or one geographical area, limiting generalisability (Lauersen et al., 2014). The approach is responsible for the over-abundance of ACL research in the field, irrespective of the merit or utility thereof (Brunner et al., 2019, Lewis et al., 2018).

The last main criticism reported is by far the most pertinent. Finch et al. (2019) have emphasised that most studies assess the efficacy (controlled environments) and not the effectiveness (real-world) of exercise interventions to make real-world injury reduction possible, as RCTs and their interventions frequently cannot simulate practical conditions or context. The sentiment is echoed by Vriend et al. (2017), who states that RCTs are not feasible for assessing background, strategic-level decisions, and general practice. Thus, rendering many studies misnomers as effectivity trial that are at best incomplete or at worse without practical benefit to the sporting community.

2.5.3 The complicated approach

The weaknesses and criticisms levelled at the traditional system can be addressed by adding complexity and refinement. The multidimensional components that injury prevention consists of could be explored and, given credence to context for the first time (Bekker and Clark, 2016). The next revolution in the research was developed by Finch (2006), creating the Translating Research into Injury Prevention Practice framework (TRIPP). The framework focuses on impacting injury reduction at the population level by extension of the old model. Additional steps are incorporated to support the transposing of the programmes' effectiveness into practice by addressing content, contexts, distribution, and execution. Implementation (step 5) and effectiveness (step 6) were included, as shown in Figure 2.3, to promote real injury reduction (Klugl et al., 2010).

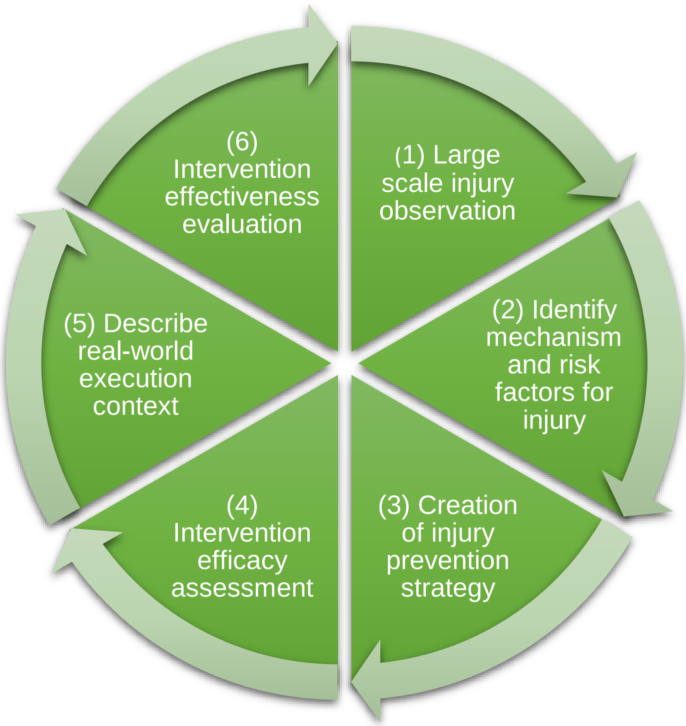


Figure 2.3: TRIPP model as presented by Finch (2006)

Both the simple and complicated approaches deem it necessary that all risk factors and injury mechanisms be concretely identified before progression (Hulme and Finch, 2015, Verhagen et al., 2018). Finch (2006) advocated a multi-disciplinary approach that emphasised behaviour and motivation components to uncover risks and mechanisms while considering biomechanical and biomedical factors. The investigation into policy modification and regulation adaption are vital components for a holistic view, however the ecological factors are still largely ignored by the literature (Hulme and Finch, 2015).

The disregard for ecological factors and complex interaction cannot be distilled down to willful neglect. The limitations and realities of performing research with finite resources need to be conceded (Cools et al., 2020, Emery and Pasanen, 2019). Studies on injury prevention would be pervasive, prolonged, and resource-intensive if strict adherence to Finch's TRIPP model were mandatory. The pragmatist approach to the dilemma is not to reject the delimitation required to make studies feasible but to design studies around these main steps. The compromise lies in constantly measuring the process against these frameworks' backdrop for a responsible approach rather than dismissal in its entirety.

Meeuwisse et al. (2007) attempted to rectify perceived deficiencies in the traditional approach and provided an alternative to a static model based on a singular causal pathway. However, the model's early attempt lacked socio-ecological determinants that Finch et al. (2019) would remedy. The model implored adopting a dynamic and recursive approach to risk and an adverse event (Bittencourt et al., 2016). The model was the first to introduce the concept that repeated exposure could alter risk factors as the individual's tissues may adapt, compensate, or fail in response (Emery et al., 2015a). This effectively rejected the construct of stable and static risk factors, questioning efficacy studies' role and value.

The complicated approach was the catalyst for the transformation of efficacy studies into effectiveness studies. The newer model's improvement is undisputed, but the complicated approach battled to deal with the actual obstacles responsible for real-world change. The criticism provided by Bekker and Clark (2016) delves into the limitations of explaining unpredictable and inconsistent outcomes as problems of execution rather than directly addressing causative issues such as adherence, value systems and fidelity. The outcome is well-conceived and complex studies fail due to some unaccounted implementation variable that the study designers never envisioned, much less measured (Pas et al., 2020).

On a practical level, the approach could encompass enhanced sub-classifications of injuries, such as re-injuries but grappled with subsequent injuries (Toohey et al., 2017, Toohey et al., 2018). The outcome was predictably a continued emphasis on modifiable risk factors, particularly the biomechanics and neuromuscular components. A more robust scientific approach was developed to direct prevention strategies at the populations with the highest prevalence rather than comparatively low-incidence injuries or very restricted groups (Bekker and Clark, 2016, Brunner et al., 2019, Hootman et al., 2007). Along with the start of a more progressive approach, the researchers should move away from a single and direct relationship paradigm (Bittencourt et al., 2016).

The complicated system prefers studies making changes on an environmental level in a population rather than merely a community-based outcome (Bekker and Clark, 2016). The socio-ecological construct is more inclusive but is still just a conceptual structure to challenge individualism intrinsic in the biomedical perspectives (Hulme and Finch, 2015); the transformation brought about a change in thought but still lacked true ecological results (Finch et al., 2019). Despite the sizeable philosophical paradigm shift, the complicated approach highlighted the need to further rework study results into executable acts that could be sustainably transposed into a sport (Emery et al., 2015a).

2.5.4 The complex system approach

The complicated approach encompassed more latent variables than ever before, but the philosophical system lacked the intricate statistical and analytic framework required to utilise the new data points realistically. Disappointingly the system could not resolve the issue of poor prediction and inconsistent outcomes (Cools et al., 2020). The research community has started to realise that the hunt for single factors, even unknown factors, could not account for the large variance observed alone (Bekker and Clark, 2016). The field was decidedly more complex than previously imagined and was starting to be compared concededly to other systems that similarly proved challenging to predict without sophisticated mathematical models such as the weather or economic markets (Bittencourt et al., 2016, Hulme and Finch, 2015).

Dissemination of concepts takes time to permeate a topic and exhibits intrinsic resistance to new notions that are not in actuality that novel. Without providing a persistent challenge to the *status quo*, researchers and clinicians will continue to hold the myopic view that athletes voluntarily select their behaviours on an individual level despite interacting in an ecological environment with other agents (Hulme and Finch, 2015). The interplay and self-organisation of agents, actions and environments will make identifying cause-effect relationships perplexing for the foreseeable future (Bittencourt et al., 2016).

Meeuwisse et al. (2007) were, as stated, the first to propose that linear systems ignore the dynamic nature of injuries, where repeated exposure to a known risk factor does not lead to a predictable injury in a susceptible individual. The repeated performance creates constant adjustment and fluctuations to the interaction of intrinsic and extrinsic risk factors, thus displaying an evident non-linear relationship and temporality (Hulme and Finch, 2015, Verhagen et al., 2018). Individuals receiving jump landing training reduce ground reaction forces and improve biomechanics by instant adjustment to their neuromuscular systems, which continue improving with more training due to a recursive loop (Lopes et al., 2018).

Bittencourt et al. (2016) vehemently proposed moving away from the unidirectional single risk factor dogma to using a complex system approach to determine injury risk profiles by identifying stable interactions. The complex system approach, diagrammatically presented in Figure 2.4, focuses on multi-factorial interaction in an open and dynamic system of heterogeneous factors.

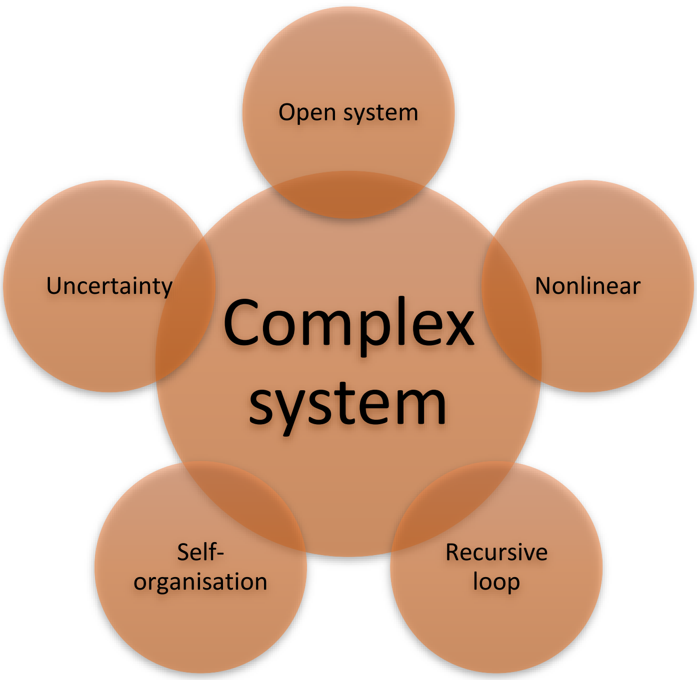


Figure 2.4: Components of a complex system summarised from Bittencourt et al. (2016)

A complex system requires investigation holistically instead of parts or a subsystem in isolation (Hulme and Finch, 2015). A criticism of system's thinking is that without access to complex analytical systems such as software, the amount of information may be unworkable for individual clinicians or researchers.

The approach is slow to be adopted as most of the existing evidence-based research is centred around a unidirectional approach, in part due to simplicity and resource limitations (Berckmans et al., 2017). Taking an ecological perspective, other risk elements outside the sports environment have not previously been considered in athletes' interactions, for example occupational variables (Nielsen et al., 2020b). The analytical capability of a complex system can allow for whole new subsystem investigations outside the scope of the specific sport or athlete into that of the individual.

Utilising a complex system approach on knee injuries, Bittencourt et al. (2012) provided conclusive evidence that dynamic knee valgus has a causal relationship with poor hip abductor strength and increased hip internal rotation, using non-linear statistical techniques. The conventional assumption that greater dynamic knee valgus is dependent on more significant weakness was not supported, and even with adequate abductor strength, dynamic knee valgus can still be present. Similarly, a single risk factor like dynamic knee valgus did not guarantee an injury emerging, indicating the importance of the interaction amongst determinates rather than the presence of a specific determinate in itself (Bittencourt et al., 2016).

The multifaceted interface of the web of determinates reveals atypical relationships different from well-known preceding studies and delivers an unconventional result that may be sport-dependent (Cools et al., 2020). The different and unexpected results are predicated on the system being fundamentally uncertain. Pragmatically, the approach is receptive to all sub-classification of injuries and is currently, the only approach which can conceptually adequately address subsequent injuries (Toohey et al., 2017, Toohey et al., 2018). The complexity of subsequent injury has organically resulted in the incorporation of technology to assist researchers by using software (Toohey et al., 2018).

The complex system recognises that an emergent effect like an injury can be due to a prior small initial event which can be counterintuitive and resistant to apparent simple solutions (Hulme and Finch, 2015). Exposing and eliciting the risk factor cause a constant adjustment to the risk and allow for fluctuations for an adverse event to materialise, which forms the basis for the performance of NMT. The fixed idea of an assigned risk percentage to an emergent event (injury) reveals a poor understanding of the possibility of the event occurring, as a range of risks would be an accurate reflection of real-world interaction (Meeuwisse et al., 2007).

A complex system can be adapted for secondary prevention strategies to integrate seamlessly if primary prevention has failed. The early application of secondary prevention measures is indicated once high-risk individuals have been injured or identified as at-risk (Emery and Pasanen, 2019). The reliability and significance of research utilising complex system approaches requires stakeholder input to find ways to quantify unknown or remove extraneous factors by the community for successful outcomes (Nielsen et al., 2020b).

Hulme and Finch (2015) conversely do not ascribe to the fervent paradigm shift proposed by Bittencourt et al. (2016) but implore researchers to supplement their reductionist methodology with complex system thinking. The supplementation or absolute utilisation of systems thinking opens new avenues for research. Interesting factors such as interdisciplinary communication and collaboration, exercise fidelity, or programme wash-out periods may be identified as part of the vital web of determinants in modern injury prevention research. The complex system approach may be a deciding factor in overcoming the present-day adversities faced by IPPs.

2.6 The adversities facing injury prevention programmes

2.6.1 Obstacles in research development and design

Meticulously conceived surveillance studies, precise capturing of information and appropriate statistical evaluation are vital components in conducting sports injury prevention research (Bahr et al., 2020). Inconsistent methodological applications and operational definitions create unreliable reportable data and decrease the community's value to that of singular study and benefit (Fuller et al., 2007, Hubscher et al., 2010). Hulme and Finch (2015) blame the causal theory for the inertia in sports injury research as the community is reluctant to embrace more modern approaches.

The pursuit of distilling statistical analyses, causative contexts, etiological constructs and system theories is an enduring process to deliver the 'best' or 'correct' method to perform injury prevention research (Nielsen et al., 2020b). The turning point may be in sight as the groundwork to develop frameworks that will enable reliable and valid high-quality research as promised by complex system adherents is being laid. Nevertheless, the field is not yet there, and it struggles with several obstacles regarding design and development.

Certain prominent factors regularly resonate throughout the limitation sections in IPP studies and the available evidence on injury research. Challenges consistently faced include poor execution, low compliance, underpowered sample sizes, extensive follow-up periods, high costs, investigator bias, recruitment bias, selection bias, and performance bias (Emery et al., 2015a, McBain et al., 2012b, Mugele et al., 2018). Poor participant and assessor blinding are widely cited and a frequently encountered limitation; however, limited studies have made genuine efforts to control and restrict the potential bias (Lauersen et al., 2018).

Studies typically show a high risk of performance and detection bias as compliance is often self-reported, with allocation concealment and randomisation techniques poorly described (Mugele et al., 2018, Plummer et al., 2019). Responses resonate with similar apprehension expressed by the authors of the prior decade as the concerns over the poor methodology quality affecting internal validity are widespread (Hubscher et al., 2010). Adverse effects are not disclosed or recorded, and unsatisfactory explanations for loss of follow-up are standard limitation in injury prevention studies (Emery et al., 2015b).

Another remnant from the traditional approach is the voluntary ignorance of baseline characteristics' dynamic nature as changes occur over time. No studies investigate changes to baseline measurements, which ideally should be measured at regular intervals as changes are expected during a longitudinal assessment, particularly in intervention groups (Emery et al., 2015a). The research populations, target interventions, sample powers and study periods differ substantially between injury prevention studies, requiring different designs (Lauersen et al., 2018).

The optimal study design in injury prevention remains an RCT (Emery et al., 2015b), but adaptations are necessary when investigating large groups such as teams.

Different forms of RCTs have proved practical in a team environment, but none more so than the cluster RCTs. Cluster randomisation can eliminate contamination bias but results in a high drop-out rate, resulting in valuable data being lost and induces its own bias (Emery and Pasanen, 2019, Rossler et al., 2018). Cluster adjustment is necessary as outcomes are more similar within each cluster than between clusters resulting in non-independence of data and overestimated statistical significance (Emery, 2007, Nielsen et al., 2020b).

Cross-over designs have been suggested as an alternative model to investigate IPPs to eliminate individual differences after a wash-out period (Emery et al., 2015a). They have worked well in equipment introduction or modification studies (Emery and Pasanen, 2019, Klugl et al., 2010, Rossler et al., 2018). Cross-over designs are exceedingly tricky to implement in exercise intervention studies, as detraining athletes would be unethical. Participants are required to return to baseline before alternative intervention is applied (McBain et al., 2012b); the only option is to postpone alternative interventions until wash-out occurs.

The statement above hides a pandora’s box that researchers have shrewdly avoided. The yet to be addressed question flowing organically after an IPP has achieved a successful and positive result, would be: “how long will it last?” Intervention effectiveness research like pharmacological studies, regards the half-lives of drugs as extremely important. This literature review scope does not allow for an extensive investigation into this subject, yet questions that should be investigated include wheter wash-out is a gradual decline process, a daily variable range or a near-instantaneous decline after training stops?

Another obstacle is that numerous reviews state the necessity to identify how IPPs achieve their effect (Hanlon et al., 2020), yet researchers rarely utilise mix-method methodologies required to identify those factors. Research by Finch and colleagues over four years demonstrated efforts to view the problem from various angles and utilise different methods and designs (Finch et al., 2016, Finch et al., 2019, Fortington et al., 2015). Without using every tool in the arsenal, it would remain unlikely to predict injuries or how successful IPPs’ prevent injury, despite the universal acknowledgement that injury prevention happens in practice.

Recommendations for utilising different methods and designs are increasing, irrespective of whether the individual studies produce lower evidence levels. Post-2000s injury prevention studies have enhanced their reporting standards resulting in higher internal validity and practice-informing research (Leppanen et al., 2014). The quality and monitoring of real-world effectiveness might still be inadequate as injury surveillance programmes have disappointedly not shown significant reductions in overall injury incidence or structure-specific injury incidence as in ACL in approximately two decades (Cools et al., 2020, Hootman et al., 2007, Huang et al., 2020).

2.6.2 The sport-specific versus generalised programme conundrum

Finch (2006) reported that proven positive results by themselves do not result in improved programme compliance or uptake from coaches. The coaches attempt to fundamentally keep the session as sport-specific as possible, as long as it is not detrimental to the athletes' well-being. The reason may lie in that sport-specific IPPs generally show a greater benefit when measuring performance enhancement in strength, power, and speed than general IPPs (Mugele et al., 2018).

No consensus exists on what characteristics make IPP’s sport-specific. However, the majority of programmes claim to be sport-specific but have a generous focus on improving fundamental and general physical attributes (Mugele et al., 2018). The literature cannot yet identify the best type of IPP as superiority trials are not the focus of research, and consequently, the optimal balance between general *versus* sport-specific components is uncertain (Sugimoto et al., 2015). Ignorant of the fact that in a complex system like injury prevention, the factors and result may be counter-intuitive as opposed to performance enhancement systems, where coaches’ expertise lies.

The participating community in IPPs has expressed a preference for sport-specific programmes which the research community seemingly ignores (Al Attar and Alshehri, 2019a). In the absence of clarity or evidence, it is recommended to cater for the populations needs to augment compliance. The general or mixed IPP with multimodal exercises appears to dominate as it is by and large successful (Mugele et al., 2018). The FIFA 11+ programme has been seen as a sport-specific programme but includes predominantly general fitness attributes and has been recommended for or implemented in other sports (Al Attar et al., 2016).

The debate may be arbitrary as the concept of movement specificity has not yet been thoroughly investigated. Various sports share specific movement patterns, and it has been argued that limited exposure to the movement patterns required by the sport could explain the higher injury risk in lower-level athletes (Mugele et al., 2018). The argument may explain why greater benefit in youth athletes is recorded with multimodal exercise interventions (Emery et al., 2015b, Faude et al., 2017, Rossler et al., 2014). Qualitative investigations into coaches' beliefs, prejudices and perspectives may illuminate additional reasons as to why coaches and athletes see sport-specificity fundamental in order to attach value to an IPP.

2.6.3 Challenges with implementation

Strategies targeting environmental factors and policy adaptation have displayed better prophylactic effect than modifications that require an individual's conduct to modify as implementation happens at higher levels (Vriend et al., 2017). Unfortunately, to date, a limited number of IPPs enjoy widespread implementation as difficulty in design and sustainability remains sticking points (Klugl et al., 2010). In Australia, the FootyFirst IPP showed no effectiveness after two years in its ecological study to measure real-world implementation using emergency room data (Finch et al., 2019).

Mugele et al. (2018) suggest that non-implementation from the participating community concerns the loss of training time. The result is that some studies create a concise programme to adapt, while others still choose to develop very extensive programmes. Selecting from the substantial assortment of exercises that provided positive outcomes and implementing the amalgamation into a consistent programme is challenging when balancing time and equipment needs (Hubscher et al., 2010). The process is deeply rooted in human resources (Fredriksen et al., 2020, Gouttebarge et al., 2020), where access to additional personnel would allow for efficient implementation.

Providing perceptible physical improvements in the short and long term can increase sustainable implementation (Plummer et al., 2019). Despite knowledge about the effectiveness of IPPs, the sporting community does not seem to divert too long before returning to implementing conventional training regimes (Mugele et al., 2018). This questions RCTs' practical value in their current form as long-term implementation is unheard of, reflecting barriers in implementation sustainability that cannot be addressed or measured by the current design (Finch et al., 2019). Keeping in mind the counter-intuitive point that due to the injury prevention paradox, low-risk groups will benefit more from IPPs than high-risk groups, and widespread implementation can potentially provide the most significant benefit to society (Verhagen et al., 2018).

The literature is quite clear that sustainable and widespread implementation problems are a prevalent phenomenon. Owoeye et al. (2020) appeal to researchers to stop testing the ability of NMT to prevent injuries but rather to assess wheter sustainable performance is likely. The focus should shift to implementation frameworks to evaluate the IPPs, not only on effectiveness but delivery and implementation. Researchers do not have to re-invent the wheel but have access to an evidence-based implementation framework already. The Reach, Effectiveness, Adoption, Implementation, and Maintenance (RE-AIM) framework was developed two decades ago and has proven its utility in numerous subspecialties (Glasgow et al., 2019). Like so many limitations in injury prevention, other fields have struggled and found solutions to the same problems.

The long-term implementation of IPPs will remain elusive without utilising all the solutions and tools available. Amongst the plethora of factors that provide hurdles to implementation, cost remains another fundamental concern. Cost analyses inform policymakers to promote intervention as improved care results from proficient use of finite resources (Emery et al., 2015a). In Australia, despite ample evidence to prevent ACL injuries and the existence of other government-funded prevention strategies for chronic ailments like cardiac disease, no musculoskeletal prevention strategies currently receive funding (Lewis et al., 2018). The implementation costs may seem high, but in the absence of economic evaluations to measure financial consequences, most stakeholders may be arguing from a place of ignorance (Emery and Pasanen, 2019).

2.6.4 Viability of Execution

Klugl et al. (2010) determined that research is conducted in environments that typically have more resources available than the target population they are determined to assist. After the study has been completed, the downside is that the target population cannot continue execution due to resource limitations. The programmes require substantial buy-in from coaches and athletes to change well-rehearsed habits, and without the capability to continue with the programme, it may breed resistance and scepticism from within the sporting community. Prospective feasibility studies should form part and parcel of the execution and delivery of the programmes, not just until inception but significantly past the prospective study's conclusion (Emery et al., 2015a).

Despite strong awareness campaigns prior to the initiation of studies of the effectiveness and benefit of IPPs, it remains distressing that generally, the execution by players remains unsatisfactory (Owoeye et al., 2020, Petushek et al., 2019). The awareness of benefits may hinder itself, as the intervention community is exceedingly reluctant to continue participation in a study if they are randomised into the control group, resulting in high numbers of drop-outs (Emery et al., 2015a). The reluctance is understandable in a competitive environment where the knowledge that other competing teams may develop an advantage results in changes in the control group's behaviour.

The researchers recognise that programmes should balance workload, intensity, time and level of effort to improve execution. Ineffectual components must be identified and removed to shorten programmes and optimally utilise training times with the participants' assistance (Mugele et al., 2018). The optimal programme consisting of only the most effective components can promote the effectual application of resources and provide better engagement. O'Brien and Finch (2016) reported that the target populations' main apprehensions do not include effectiveness or perceived lack of value, but the loss of training time, lack of variation and adaptability.

Real-world uptake requires full engagement of the whole sporting community seeing that notwithstanding the research community's enormous support to prevent ACL injuries, the rates have not decreased (Petushek et al., 2019). The different agents and their interactions have not been considered as the participation community's support does not correlate with execution. One suggestion to improve execution on a participant level is to design an ideal programme with different levels in order for the athlete to progress the difficulty and stay challenged (Emery and Pasanen, 2019). Improving buy-in from the participants as opposed to the coaches can enable less supervision being required to keep .

The coaches may support the programme, but the execution will be mediocre without a concerted effort from the players. The critical component of execution from a participant perspective is exercise fidelity. The basic premise is that the effectiveness and benefit can only be reached or studied optimally if the exercises are performed as described. Fidelity is rarely investigated, and in one of the few studies that did, exercise fidelity was low, with more than half of the exercises not performed as prescribed (Ljunggren et al., 2019). Coaches implement modified versions of evidence-based IPPs with added variations to create levels of progression, individualisation and make the programmes more enjoyable, resulting in unsatisfactory fidelity (O'Brien and Finch, 2016).

On the other hand, if merely moderate fidelity can be expected, the dosage should be adjusted to compensate for it. The dose-dependent response is well recognised within injury prevention research and will affect the outcomes (Lauersen et al., 2018, Rossler et al., 2014). The participating community is aware that optimal dosage is at best, currently imprecise and coupled with the improper recording of exercise duration and frequency (Crossley et al., 2020) it dissuades long-term execution due to ambiguity or lack of visible results.

Two options are available at present, with the latter showing more promising. The first is to overdose and increase the volume, accepting that only the minority will be exposed to high acute load increases if performed as prescribed and may increase their risk of injury (Gabbett, 2016). The second is to develop more sensitive measures to account for accumulative doses, thus improving recording precision. Dose measurement and recording can be done utilising the already widely available technology, like activity trackers or web-based applications.

Limited studies investigate catalysts and obstacles for performance, resulting in a poor understanding of the execution environment and the prospective moderators involved (Owoeye et al., 2020). Real-world integration mandates a workable execution framework to enable successful buy-in from coaches, athletes, support staff, medical staff and policymakers. The potential and inestimable value of IPPs remains meaningless to a population or the greater society if undermined by inaction; in this failure to act it remains merely research.

2.6.5 Shortcomings in statistical analysis

Mugele et al. (2018) reported that standardised methods to calculate injury incidence do not exist, and a wide variety of methods are used to analyse data in the field. The selection of the best-suited techniques is fundamental in interpreting outcomes (Emery et al., 2015a); incorrect methods can result in entirely erroneous results. If an analysis is designed around a simple system approach, it hinders the investigation into variables as the outcomes are directed at examining the entity (injury) rather than the sum of its parts (Bekker and Clark, 2016).

Injury prevention research has a copious number of systematic reviews, but the high level of heterogeneity coupled with diverse statistical methods makes comparisons of different exercises or results challenging (Asker et al., 2018, Mugele et al., 2018). Typically, the meta-analyses' results fail to achieve statistical significance despite individual primary studies reporting a significant prophylactic effect (Leppanen et al., 2014).

Regularly, sub-group analyses performed as part of a meta-analysis are underpowered to detect an effect (Faude et al., 2017), yet results are presented without cautioning the reader regarding its certainty. Accredited peer-reviewed research journals now demand that a Grading of Recommendations, Assessment, Development and Evaluation (GRADE) summary of findings is included with meta-analyses in order to address the problem (Mustafa et al., 2013).

Missing data is a significant problem due to the large chunk of missing data generated by the high number of drop-outs or censoring in studies (Nielsen et al., 2020b). An incomplete collection of all data is an ever-present constraint in injury prevention RCTs which requires enhancement in the transparency of reporting regarding ineligible participants, drop-outs or withdrawals with reasons (Emery et al., 2015a). Leppanen et al. (2014) caution taking results at face value due to problems with internal validity of studies selection bias (due to lack of blinding), performance bias, co-interventions and low compliance, attrition bias caused by a lack of intention-to-treat analysis (ITT) or unacceptable drop-out rate.

Post-data collection problems continue to arise when statical models do not consider the mathematical adaptations that different designs need. Lauersen et al. (2014) and Emery (2007) criticised the lack of cluster adjustment in the studies and the omission of a proper ITT analysis. The quality of injury prevention statistical models and the inherent problems with internal validity bring the phrase *caveat emptor* to mind, and studies merit more than perusal before the research can be accepted.

Asker et al. (2018) highlight the small sample sizes regularly found in primary studies which preclude assertions from being made on causal relationships and fall prey to type II errors. Poor follow-up does not allow for long-term effects to be documented or conclusions to be drawn, reducing long term results. Many primary studies suffer from inadequate sample sizes, a lack of prospective sample power and insufficient modification for confounding factors (Emery et al., 2015b, Emery and Pasanen, 2019, Leppanen et al., 2014). The systematic reviews and meta-analyses performed by these studies will suffer from the inherent issues that colloquially became known as 'garbage in, garbage out'.

Nielsen et al. (2020b) encourage greater collaboration with the biostatistical community, researchers, and multidisciplinary experts, to develop a higher quality of statistical training for all entrants into the field. The ideal environment to translate efficacy research to effectivity includes identifying the relevant contextual factors while using a multidisciplinary approach (Hulme and Finch, 2015). The enhancement of sports injury prevention relies on consistency in paradigms and approaches utilising similar analysis methods (Bittencourt et al., 2012). The inclusion of a statistician as part of the research development phase will soon become the minimum standard; that such an exclusion will become conspicuous (Bahr et al., 2020, Nielsen et al., 2020b).

2.6.6 Improper monitoring and reporting

The extent of monitoring has progressed to the stage where a wide range of sports, competitive levels and settings have seen the implementation of routine injury surveillance (Bahr et al., 2020). Traditionally studies divide injury incidence into anatomical sites or the enduring standard of the upper extremity and lower extremity split. The inconvenience becomes apparent if match and training injuries are recorded collectively instead of individually and this, coupled with different incidence recording makes a comparison between studies impossible (Mugele et al., 2018).

Sport-specific consensus statements have been successful in systematically providing an outline on how to report injury prevention data (Fuller et al., 2006, Fuller et al., 2007). The advantage that sports level formalisation creates is that similar data sets enable investigation of specific conditions, like the number of finger sprains sustained during matches, without the data being trapped in pools like upper extremity or overall injuries. An official guideline allows standardisation and comparison, which provides for formally correct data but does not guarantee it is substantively correct.

The person identifying injury is an essential part of the research and as the current trend of coaches, managers, or internal medical staff as first contact introduces new potential biases. The injury incident recorder is a critical design element that can either bolster internal validity or reduce it (Nielsen et al., 2020b). The agent responsible for data collection may bias the result due to overestimating or underestimating injury (Hubscher et al., 2010). The data can be collected *via* self-reported questionnaires, coaches, or medical staff. Ideally, the data capturer should be an independent, blinded party. Fuller et al. (2006) recommended more than a decade ago that data collection forms be standardised and consistently tracked throughout the study.

Allowing involved and non-blinded agents to collect data is mostly due to operational and logistical limitations. Regrettably, each party is prone to suffer from different biases. The athletes' injury may be down-played to allow faster return to sport for a critical position or create a culture of toughness and loyalty, resulting in an environment where recording is done reluctantly and half-heartedly (Nielsen et al., 2020b). The option of allowing the athletes to self-report injuries open the door to the development of recall bias and injury misclassification documentation (Andersson et al., 2017, Hubscher et al., 2010).

A reporting bias may exist in the studies as almost wholly traumatic or acute injuries are being investigated, with spare information on overuse injuries (Brunner et al., 2019). Illness monitoring is often lacking in injury surveillance programmes; however, modifying less than 20% of training weeks can reduce illness risk (Raysmith and Drew, 2016). A recent consensus statement has once more acknowledged that a renewed focus on overuse injuries and illness in sport is required (Bahr et al., 2020).

Considering that the quality and fidelity of IPPs are increasingly required to be monitored rather than only measured. Workload over a period would produce a more scientific and more rigorous measure than exposure hours as a variable for the load (Emery and Pasanen, 2019). The ideal system should decrease manual recording and monitoring for a feasible and sustainable automated process. Producing uninterrupted and high-fidelity monitoring raises the bar on acceptable reporting principles and data capturing.

2.6.7 Deficiency in compliance

The elusive pursuit of high compliance is an ever-present thorn in the side of injury prevention research (Asker et al., 2018, Cools et al., 2020, Emery et al., 2015a, Finch, 2006, McBain et al., 2012b, Mugele et al., 2018, Plummer et al., 2019). The development of IPPs in football was plagued with poor compliance with the first incarnation of the official football injury prevention program, namely the Fédération Internationale de Football Association Medical and Research Centre (F-MARC) “11” (Al Attar et al., 2016).

Cools et al. (2020), like so many other researchers before, state that compliance with exercise interventions is the *most critical* requirement for a successful outcome. Notwithstanding, the relationship between high-level compliance and greater prophylactic effect being verified; it remains challenging to motivate coaches and athletes to follow-up and follow-through (Caldemeyer et al., 2020, Leppanen et al., 2014). Education of coaches and effective marketing to the sporting community are a proposed solution to reduce reluctance and boost compliance (Al Attar et al., 2016).

Compliance and programme fidelity totals should be thoroughly assessed to reveal the actual effectiveness of IPPs and published prominently with the results (Mugele et al., 2018). Compliance data is routinely collected *via* self-reported measures, which can be biased (Plummer et al., 2019). Using a proxy measure like attendance is a flawed method to measure adherence as it is at best, an indirect measure of effort (Emery et al., 2015a). Techniques regularly employed to deal with compliance are supervision, coach instruction, providing written material, and asking participants to diarise (Lauersen et al., 2018).

The first portion of compliance relates to adhering to performing the program as described, and the second portion is compliance with providing data capturing. Plummer et al. (2019) suggest that emphasising the possible performance enhancement may help change the sporting community’s attitudes and beliefs regarding the consistent application and recording of IPPs. Written instructions with examples of data collection forms, designating a program liaison, maintaining frequent contact and providing regular feedback can improve data capturing compliance (Fuller et al., 2006).

A dose-response is well established in the literature, providing no other option for researchers than to formally measure and report non-compliance as it severely influences the results (Caldemeyer et al., 2020, Lauersen et al., 2018, Rossler et al., 2014). Emery and Pasanen (2019) describe a superior IPP as a universally embraced programme by athletes, coaches and sporting federations that leads to sustainable execution and high adherence. The art will consist of safeguarding the equilibrium of evidence on the one hand and practical implementation in context on the other.

2.7 An overview of injury prevention programmes

2.7.1 Types of injury prevention strategies

Contemporary research trends advocate primary injury prevention strategies such as NMT, rule amendments and gear alterations in at-risk populations to limit lower extremity injuries, particularly for active youths and adolescents (Emery and Pasanen, 2019). The recognised strategies to reduce injury in military personnel include overtraining prevention, implementation of NMT, increased awareness from the side of leadership regarding injury burden, and enhancing physical fitness (Dijksma et al., 2020). Psychological or cognitive training and education to prevent injuries are under-researched in the literature (Vriend et al., 2017).

Supplementation intervention has not been thoroughly investigated and is receiving some attention, but only in particular populations (Emery and Pasanen, 2019). However, several studies investigating calcium and vitamin D supplementation have shown a reduction in stress fractures in female military personnel (Gaffney-Stomberg et al., 2019, Lappe et al., 2008). The research on nutritional supplements is not geared to investigate a relationship with injury or injury risk at this stage.

A prevention strategy may be tailored to an individual level or at a contextual level (Vriend et al., 2017). Protective equipment modification, policy adjustment and training interventions are recognised strategies to protect athletes from injury working on different levels (Emery and Pasanen, 2019). A summary is presented in Figure 2.5. Vriend et al. (2017), using a Haddon Matrix, classified strategies into those that influence the host (athletes), agents (rules and regulations or equipment), settings or context (environment), or a combination of the above.

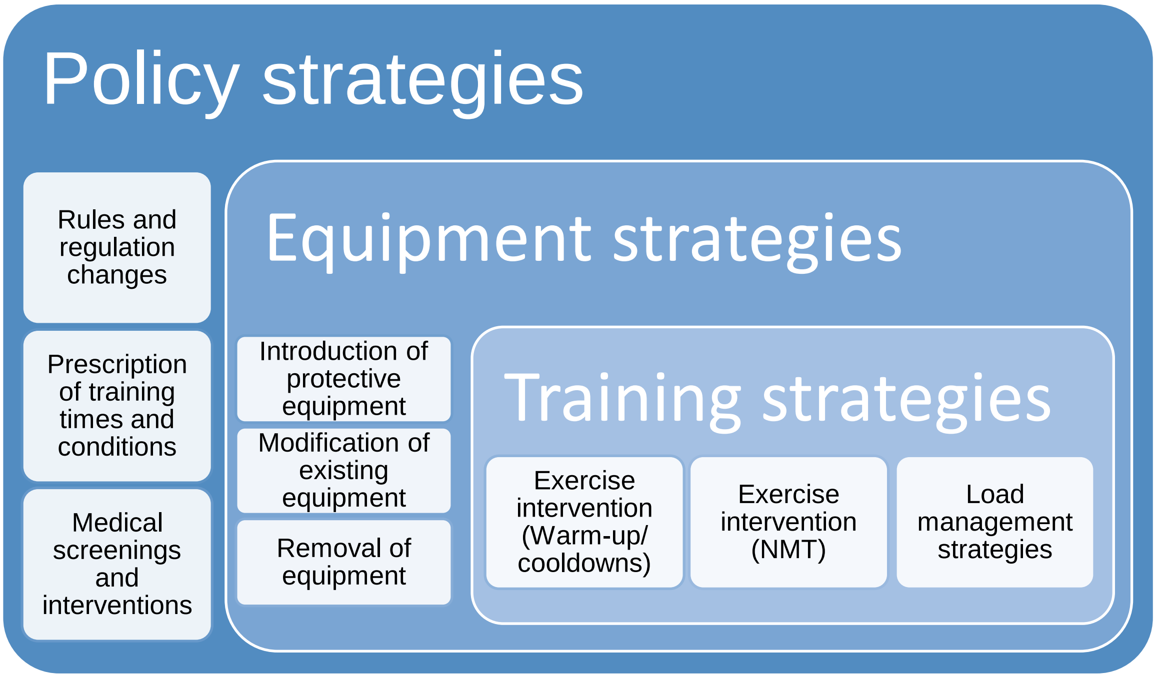


Figure 2.5: Injury prevention strategies summarised from Emery and Pasanen (2019)

Hootman et al. (2007) proposed policy adjustment to aid in injury prevention recommending phased or multi training sessions be utilised; adapting practice hours to environmental conditions; prescribing mandatory recovery times and protocols; and continued medical screenings. Limited studies have investigated the influence of rules and regulation changes to reduce sports injury, which remarkably surpass even the best outcomes for training strategies (Emery and Pasanen, 2019, McBain et al., 2012a). Changes to rules and regulations have been shown to reduce injury by up to 50%. It is, unfortunately, a process marred by slow progress and bureaucratic red tape as implementation requires organisational changes at a regional or national level (Hootman et al., 2007, Mugele et al., 2018, Vriend et al., 2017).

Protective equipment inclusion or modification has been shown effectivity in particular sports and within certain conditions. The equipment research is regularly industry backed to prove efficacy and promote use (Klugl et al., 2010, McBain et al., 2012b). Initial RCTs in injury prevention centred around personal protective equipment such as braces and insoles, which showed positive effects (Leppanen et al., 2014). However, the uptake is less than optimal without the support of educational strategies and policy adjustment in a sporting organisation (Bahr et al., 2020). The slow voluntary use of protective equipment, unless mandatory for participation, has caused the stagnation of research into protective equipment.

Two team sports have amassed the most evidence on injury prevention research, with the inclusion of various injury prevention strategies directed at different levels. Football has emphasised exercise intervention, while rugby emphasises rule-changes and using protective equipment (Vriend et al., 2017). Rugby specific research has confirmed that headgear or mouthguards were not effective in moderating the rate of concussions sustained during contact (Leppanen et al., 2014). Football, being the most researched sport regarding injury prevention, has positively affected the players' psyche in so far as almost all professional footballers share the view that IPPs should permanently form part of their training (O'Brien and Finch, 2016).

High-quality systematic reviews have left no doubt about the effectiveness of exercise intervention programmes to potentially prevent and limit lower extremity injuries in both children and adults after a continued performance (Caldemeyer et al., 2020, Dijksma et al., 2020, Faude et al., 2017, Huang et al., 2020, Lauersen et al., 2014, Petushek et al., 2019, Rossler et al., 2014). According to the facts, the training strategies are not the most efficient or most uncomplicated method to prevent injury, but are undoubtedly the most popular, particularly in team sports (Al Attar et al., 2016, Crossley et al., 2020, Owoeye et al., 2020).

According to Emery et al. (2015b), all strategies should fundamentally accomplish two primary principles. Firstly, they must provide evidence of a protective effect. Secondly, they must be able to improve policies or current practice for the betterment of the community. The strategies to prevent injury and allow participation are universally recognised as a prospective investment in health in that they prevent disabling sequelae such as obesity and post-traumatic osteoarthritis (Emery et al., 2015a, Emery and Pasanen, 2019).

2.7.2 Types of training strategies

Contrary to expectation, low fitness levels are a better prognostic indicator of mortality than obesity or hypertension, justifying intense scrutiny of injury training strategies like IPPs to assist in promoting physical activity (Emery et al., 2015a, Khan et al., 2012). The IPPs are commonly utilised as a part of either a warm-up session, cooldown session or more uncommonly, as an additional session (Cools et al., 2020, Emery and Pasanen, 2019). Programmes can differ from each other in that they either replace a total portion, as with the FIFA 11+ (Rossler et al., 2018), supplement a part of training with specific exercises (Andersson et al., 2017), add a single extra exercise like a Nordic hamstring curl (Huang et al., 2020) or add a new supplementary session (Pas et al., 2020).

The warm-up model is by far the most popular, particularly in team sports, as the sessions can be supervised and last approximately 15 minutes to 20 minutes (Al Attar and Alshehri, 2019a, Faude et al., 2017). According to McCrary et al. (2015), a warm-up is performed in preparation for ensuing bodily action using a particular procedure. The ability of warm-ups to reduce injury has produced mixed results in the past, but has shown positive results when data is pooled (Leppanen et al., 2014). Warm-ups were previously poorly researched, as the entity and not the content, was evaluated. Modern programmes now include evidence-based exercises, resulting in consistent findings.

Al Attar and Alshehri (2019a) in their meta-analysis, found that all the different incarnations of the FIFA warm-up protocols reduced all injuries with 34% and lower extremity injuries with 29%. Whole-body and lower extremity warm-ups have shown the ability to prevent injury and enhance performance (McCrary et al., 2015). Training strategies for the upper extremity are lacking in general (Emery and Pasanen, 2019). McCrary et al. (2015) confirm this as no research on the ability of upper body warm-ups to reduce upper extremity injuries exists.

Training interventions include well-designed specialised warm-ups or neuro-muscular training (NMT) (Dijksma et al., 2020, Khan et al., 2012). The literature is divided on whether all warm-ups are IPPs or if all NMT are IPPs: in order to avoid confusion, this dissertation will treat all as unique entities. The neuromuscular component's attention within injury prevention protocols has become so intense that most programmes term any injury prevention exercise as NMT, irrespective of the component classification.

The warm-up protocols used in football aim to bring about neuromuscular adaptations by including NMT with added strength, technique, power and balance exercises (Al Attar and Alshehri, 2019a). The statement above has packed three types of training strategies into a single model in so far that warm-ups, NMT and IPPs have blended into one. IPPs are most commonly designed to consist of multimodal exercises to target neuromuscular deficiencies (Faude et al., 2017).

Load management or adjustment strategies have not gained traction in the many IPPs (Hootman et al., 2007, Mugele et al., 2018, Vriend et al., 2017). The programmes tend to add extra and not remove what is redundant. Training loads have an ideal range as workloads that are too high or too low have been linked to increasing the risk of injury (Gabbett, 2016). The assumption that excessive training loads induce overuse injury is incorrect; fast surges of acute load above the athletes' threshold is the contributing factor (Gabbett, 2020).

The evidence on injury prevention regularly overlaps with performance enhancement research. Misunderstanding can easily occur as studies can generate improved physical performance without impacting injuries and *vice versa*. Examples include performance improvement recommendations like performing additional sessions of NMT for than 30 minutes which can improve balance, strength, power, endurance and agility measures (Plummer et al., 2019). Simultaneously, high load dynamic warm-ups are superior to low loads to boost power and strength in the upper and lower extremities (McCrary et al., 2015). The training strategy of applying IPPs incorporating NMT is the principal area of investigation.

2.7.3 An outline of neuromuscular training

The majority of studies examining preventive programmes that seek to enhance universal physical attributes, sport-specific skills, or injury prevention, have become synonymous with NMT (Vriend et al., 2017). NMT research is typically performed in formalised team sports, with increasing attention to younger athletes (Emery et al., 2015b, Emery and Pasanen, 2019, Owoeye et al., 2020, Rossler et al., 2014, Rossler et al., 2018). NMT is theorised to alter and modify intrinsic risk factors or physical qualities to promote safe exercise and participation (Emery et al., 2015b, McBain et al., 2012a).

A substantial evidence base supports the use of NMT warm-ups and prevention protocols to decrease musculoskeletal injury risk and incidence by between 35% to 50% (Emery and Pasanen, 2019, Finch et al., 2019, Khan et al., 2012, Owoeye et al., 2020). In organised youth sports, the rate of injury reduction is between 40% and 48%

(Emery et al., 2015b, Faude et al., 2017, Hanlon et al., 2020, Owoeye et al., 2020, Rossler et al., 2014). The positive outcomes aside, the popularity of NMT can be attributed to the fact that no supplementary equipment is required, it is low cost, and it is easy to implement (Leppanen et al., 2014).

The abundance of systematic reviews has reported some conflicting results on the effectivity of NMT to prevent overuse injuries. Initial reviews could not provide a conclusion as inadequate evidence existed on either non-contact or overuse injuries (Klugl et al., 2010, McBain et al., 2012a). Later NMT proved effective in preventing acute and overuse injuries in the lower extremity, reducing almost half of all overuse injuries (Lauersen et al., 2014). Unexpectedly in the umbrella review by Brunner et al. (2019) of all available systematic reviews, no conclusion could be made on overuse injuries based on insufficient data.

The prevention effect extends not only to overall injuries (albeit focused on the lower extremity) but also to specific injuries or anatomical sites like the knee and ankle for adult and youth athletes alike (Brunner et al., 2019, Rossler et al., 2014). IPPs can reduce knee and ACL injuries by 50 - 80% (Huang et al., 2020, Lewis et al., 2018, Petushek et al., 2019) and reduce ankle injuries by 38-66% (Caldemeyer et al., 2020, Mugele et al., 2018). In child and adolescent sport, females benefit from a greater effect compared to males when participating in NMT (Rossler et al., 2014).

The bulk of research centres around changing the athlete's training behaviour in the pre-event or pre-season stage utilising preventative exercises (Vriend et al., 2017). Injury surveillance programmes have shown higher injury rates during pre-season (Hootman et al., 2007, Lewis et al., 2018), coinciding with the most popular time to implement an IPP. Investigations on injury reduction in collision sports are by and large devoted to exercise interventions to minimise head, neck and spine injuries (McBain et al., 2012a).

Despite the lack of enthusiasm shown in compliancy and execution; it is suggested that if the reduction does not convince teams of injury or possible performance improvement, the potential competitive advantage over a season should (Al Attar et al., 2016). Injury and illness prevention in the six months prior to a main event are vital to increase the chance of success (Raysmith and Drew, 2016). Football has fully embraced the utilisation of IPPs to gain a competitive edge by either performance enhancement or player selection availability. NMT warm-ups are the most common type of IPP in football and can reduce injuries across all demographics and sexes (Crossley et al., 2020, Owoeye et al., 2020).

Al Attar et al. (2016) reported that several football studies provide contradictory outcomes due to insufficient sample sizes and statistical insignificance. However, their meta-analysis found that the pooled effect of the F-MARC IPPs can decrease overall and lower extremity injuries by 20% to 50%. The updated FIFA 11+ IPP can decrease overall injury incidence by between 43% to 50% (Al Attar and Alshehri, 2019a), the updated programme not revealing a greater effect but a more consistent effect. Conversely, Crossley et al. (2020) found a less protective effect in female footballers, with an overall injury reduction of only 27% and reduced ACL injuries by 45%.

The implementation of NMT at a different time in a season, e.g. pre-season, in-season or post-season, resulted in similar effects for youth athletes (Rossler et al., 2014). The time required for a result is highly variable between six weeks to six months (Caldemeyer et al., 2020, Hubscher et al., 2010), with some using 20 minutes thrice-weekly sessions (Lewis et al., 2018) and others using one to seven sessions per week for between five to 30 minutes (Caldemeyer et al., 2020, Hubscher et al., 2010). The question as to when NMT achieves the threshold for a positive result remains unknown. Regular studies retest after at least six weeks, resulting in our current literature base and continued *modus operandi* for prospective studies.

2.7.4 Elements of neuromuscular training

The literature provides no definitive definition for NMT. A universally accepted consensus on the definition will assist in delimiting the elements and provide the ability to compare similar research holistically. Unfortunately, the current state is somewhat chaotic with various authors using the same definition for different components and others misclassifying components (Brunner et al., 2019). Considerable inconsistency exists in the actual content (specific exercises) and the application methods between different programmes (Faude et al., 2017, Huang et al., 2020, Hubscher et al., 2010, Sugimoto et al., 2015). The consequence is significant difficulty in correlating studies and, in particular the systematic reviews on the subject.

According to Lauersen et al. (2014) and Petushek et al. (2019), IPPs can historically be categorised into five main components (Figure 2.6): Stretching/flexibility, jumping/ plyometrics, balance/proprioception, strength training or a combination/multimodal exercises. The literature implies that NMT may be a synonym for multi-component exercises or that two or more components in a single IPP may result in an NMT classification. Faude et al. (2017) prefer to term programmes consisting of agility, balance, power and strength as NMT. There is no present-day consensus on what combination constitutes NMT, while most authors claim their programmes are NMT.

Interestingly, Sugimoto et al. (2015) included a novel umbrella component called proximal control exercises, referring to a wide variety of NMT exercises and found it effective to prevent ACL injuries. Huang et al. (2020) provided best-evidence guidelines for ACL IPPs, and advised NMTs must consist of agility, plyometric and strengthening exercises, as they were the common denominators in studies with a positive result. Dijksma et al. (2020) on the other hand, prefers to view NMT as bodyweight exercises and includes agility training in the definition, while resistance training is not included and is defined as weighted by external loading equipment like weights or bands. Attempting to provide a working definition of NMT is problematic due to the two distinct approaches identified in the literature.

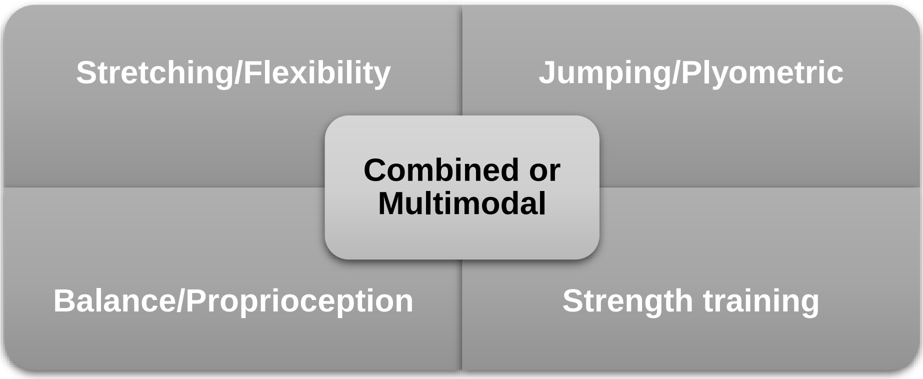


Figure 2.6: Typical components of IPPs summarised from Lauersen et al. (2014) and Petushek et al. (2019)

The first approach is a general focus on multimodal exercise intervention to prove the capability to prevent injuries and thus, as a total entity requires no operational NMT definition (Emery and Pasanen, 2019, Caldemeyer et al., 2020, Faude et al., 2017, Rossler et al., 2014). The second approach is a specific focus on identifying the value of each individual component which requires delimitation of NMT and as such, some definitions on the components investigated (Dijksma et al., 2020, Lauersen et al., 2014, Lauersen et al., 2018, Petushek et al., 2019, Sugimoto et al., 2015, Sugimoto et al., 2016).

The combination of NMT components has shown the ability to reduce the risk of acute lower extremity injuries except in the case of stretching exercises (Dijksma et al., 2020, Lauersen et al., 2014, Petushek et al., 2019) and core stability exercises (Dijksma et al., 2020, Petushek et al., 2019). Programmes consisting of stretching, core exercises, balance or agility were not more effective than those protocols that excluded them in ACL injury prevention (Petushek et al., 2019, Sugimoto et al., 2015). The literature clarifies that NMT can reduce and prevent injuries, but the component of NMT that is responsible for this effect is currently not clear.

The preventative effect of NMT is superior in novice athletes compared to high-level athletes, possibly due to a ceiling effect (Rossler et al., 2014). Similar findings were found by Dijksma et al. (2020) in military recruits *versus* experienced active members; this should be interpreted with caution as military trainees have a greater focus on physical activity than active-duty personnel. While in youth athletes, a surprising and counter-intuitive finding was that larger effects were reported in higher-level athletes (Faude et al., 2017).

The subsequent challenge to define NMT is establishing exactly the components it consists of and then weighing each individual component within the training protocol. The approaches divaricate into either a single component programme (strength only) or a small part of the whole as a catch-all approach (multi-component protocols). The instinctive approach is to add a little bit of every component to cover all the bases with the added expectation that only the best effects will be elicited in interaction with each other.

Petushek et al. (2019) pointed out that proprioception, core, flexibility and agility exercises are likely not harmful but constitute an inefficient use of time, energy and resources. Reduction of efficacy and diminished compliance is a consequence of indiscriminately adding one or more additional components into an IPP for the sake of completeness (Lauersen et al., 2014). Thus, a comprehensive catch-all approach seems to reduce effectiveness and not improve outcomes. The sums do not make up the whole.

Adding more components can reduce the intensity and specificity required to contribute to a positive change. The hidden danger is not in reduced effectivity but potential adverse effects. In military trainees, studies that added balance and agility or core training respectively, as an additional component of their basic training resulted in a possibly harmful effect with an injury risk increase of 25% (Dijksma et al., 2020). Sugimoto et al. (2015) similarly found that when balance exercises were included, the effectiveness to reduce ACL injuries dropped from 66% to 41%. Dijksma et al. (2020) theorised that the increase in training load might be responsible for the increased risk.

The ability to change or influence movements after a prolonged intervention is fundamental to the methodology applied to rehabilitation and injury prevention. The resulting improvement in performance after the intervention is a foundation of the musculoskeletal therapeutic approach (Lauersen et al., 2018). The approach follows inductive reasoning with reductionism. If the parts, i.e., the muscles, increase in strength and performance over time, then the whole, i.e., the motor/functional pattern, will causally improve in equal measure.

2.8 Specific components of neuromuscular training

Mugele et al. (2018) recommended that RCTs be used as a specific vehicle to investigate the superiority of specific exercises from previously proven IPP to determine their efficacy. The wide variety of exercises and implementation frameworks differs so substantially across IPPs that comparison may not be possible; nonetheless, it does not preclude superiority trials (Huang et al., 2020). A universally optimal exercise or combination of exercises to prevent injury does not exist, nor can it be agreed upon (Mugele et al., 2018).

Vriend et al. (2017) identified that training programmes, in general, constituted the most substantial portion of injury prevention strategies and the interventions consisted of strength (58%), proprioception (45%), flexibility (31%) and plyometrics (30%). McBain et al. (2012b) reported that efficacy studies include balance and proprioception (54.9%), resistance training (43.1%) and flexibility (15.7%). Further, McBain et al. (2012a) discovered that effectiveness studies mostly included multimodal exercises, with the majority including balance training (63.3%), strength and power (36.7%), and the minority included flexibility (22.5%). A modified component of IPPs diagramme is introduced below in Figure 2.7.

Brunner et al. (2019) highlighted that proprioception and strength in adult athletes' programmes are the most common combination of elements in NMT. While in youth athletes, the components of strength, proprioception and agility are pervasive (Emery et al., 2015b). Hanlon et al. (2020) investigated performance attributes in youth athletes and found the most remarkable changes were in strength and then co-ordination after programme completion. The focus on strength, co-ordination, balance, posture and power is similar to other reviews but has been criticised for excluding endurance and psychological states.

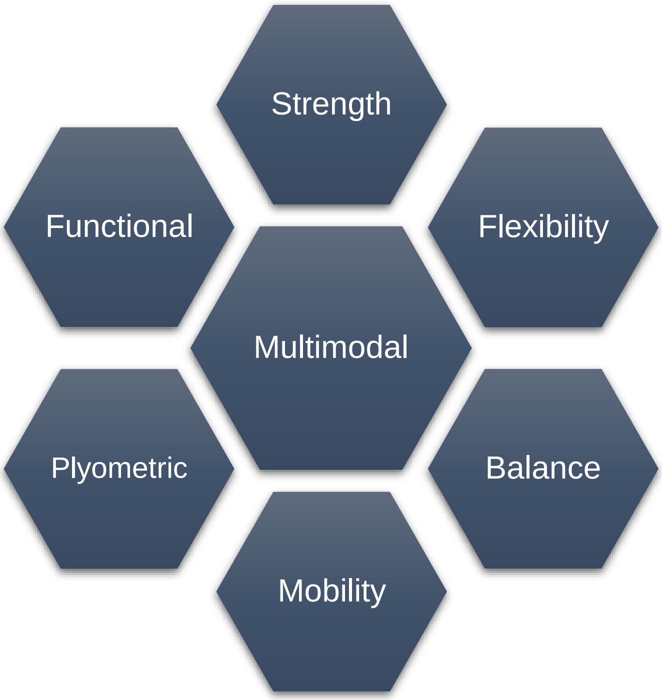


Figure 2.7: Modified components of IPPs

Recommendations for future research advocate investigating which components and dosages are more prophylactic rather than comparisons to conventional practice (Al Attar et al., 2016). Research that poorly describes exercises can lead to misclassification resulting in inadequate reproducibility and the increased risk of reporting bias (Faude et al., 2017). Variance in exercise component selection and classification restricts the production of best-practice guidelines to deliver optimal injury prevention (Petushek et al., 2019). The task at hand is to examine each component meticulously and systematically to determine its value and utility in context.

2.8.1 Strength training

Strength exercises are defined as any form of isotonic weight or resistance training with the goal to increase muscular force generation by use of bodyweight, free weights, bands or machines and includes core stability training (Brunner et al., 2019, Taylor et al., 2015). Strength training and resistance training are used interchangeably in the literature. Some studies tend to differentiate between callisthenics and resistance training by allocating callisthenics to bodyweight NMT (such as push-ups) and resistance training to weighted NMT (TheraBand punches), further muddying the waters (Dijksma et al., 2020).

Callisthenics is commonly classified as bodyweight exercises, but a more accurate description would be that callisthenics is a form of resistance training that can effectively improve strength by using one’s body weight as resistance (Kotarsky et al., 2018). The term strength training is preferable as this is the main aim of these training forms, resistance training with weights being the most obvious method, while callisthenics is another recognised method.

Research into strength training’s ability to influence injury has been steadily increasing since the early 2000s (McBain et al., 2012a). An earlier systematic review and meta-analysis by Lauersen et al. (2014) revealed an indication of the superiority of strength training only protocols over multimodal protocols irrespective of whether the other protocols also included a strength training component. This superiority was definitively established by their subsequent systematic review and meta-analysis (Lauersen et al., 2018). The finding is corroborated by Petushek et al. (2019) in developing best practice guidelines for preventing ACL injuries in young females (Huang et al., 2020).

Strength increases do not necessarily occur in multimodal NMT programmes as in the FIFA 11+, as the duration is too short to stimulate strength gains (Mugele et al., 2018). However, in youth IPPs a medium increase in leg strength was reported after an extended performance (Faude et al., 2017). The prophylactic effect through multimodal exercises is not the same mechanism responsible for strength training’s effects and thus, the strength components in multimodal exercises cannot claim sole responsibility for a preventative effect. This is particularly true for any short-term benefits as strength training requires prolonged performance to induce changes.

High-quality reviews (Dijksma et al., 2020, Finch et al., 2019, Lauersen et al., 2014, Lauersen et al., 2018, Petushek et al., 2019, Sugimoto et al., 2015) found that strength training prevents acute injuries more effectively than neuromuscular multi-component programmes, particularly in the lower extremity. Lauersen et al. (2018) declared that the preventative effect is of similar magnitude for overuse injuries; this should be interpreted with caution as the statement is based on only two studies in their meta-analysis. Strength training protocols alone result in a 66% reduction in sports injuries with an excess of 50% risk reduction over eight months (Lauersen et al., 2018, Petushek et al., 2019).

Strength training proves to be one of the principal components of injury prevention, even in studies where component superiority is not directly investigated but later identified in subgroup analyses (Brunner et al., 2019, Huang et al., 2020, Leppanen et al., 2014). A direct causal relationship exists between strength training and the prevention of injuries. After completing a strength training IPP, the individual has an up to 57% risk reduction (Lauersen et al., 2018). While in military recruits, a strength-focused injury prevention protocol had a relative risk (RR) reduction of approximately 34% (Dijksma et al., 2020).

In ACL IPPs; Nordic curls, lunges, and calf raises were superior at reducing injury risk when included (Petushek et al., 2019). The Nordic curl is one of the most popular strength exercises in ACL prevention programmes for females (Sugimoto et al., 2015) and has been an intense research focus in recent years as a single exercise intervention programme. Caldemeyer et al. (2020) advise that NMT programmes should not only provide site-specific training but include strengthening of legs, hips and core.

NMT in football comprises to a large extent of self-classified strength training components. Only 30% of included “strength” exercises meet the criteria when measured against recognised guidelines for strength training (Crossley et al., 2020). Strengthening exercises require enough load and specificity over an extended timeframe to produce gains. Comparable issues are found in mixed programme warm-ups as they fail to show an improvement in strength because the stimulation threshold is too low and the duration is too short to cause improvement (Plummer et al., 2019).

The dose-response to IPPs has now been regularly cited and found to have an inverse relationship (Bittencourt et al., 2016, Huang et al., 2020, Rossler et al., 2014, Sugimoto et al., 2016). An interesting *caveat* on the dose-response relationship was reported by Lauersen et al. (2018) that showed increasing the volume and intensity of strength training showed a significant positive correlation to injury reduction but not protocol duration. The programmes' duration ranged from 10 to 39.9 weeks, with an average of eight months (Lauersen et al., 2018). Petushek et al. (2019) found the sessions averaged 57 sessions with a total time of 18.17 hours. The finding correlates with exercise fidelity as what matters is the concentration and amount, not so much the length of application.

The conclusions and recommendations have been inferred using fixed data points for the continuous variable of strength, the suitability of which has been questioned. Bittencourt et al. (2012) propose that changes in strength during a season may be more predictive than one absolute value measured at a specific point in time. The repeated measure and utilisation of averages or means will lessen the variability compared to static measures. A predictive model can be built by data profiles gained by regular assessment of cohorts in longitudinal studies.

Multimodal exercise programmes' popularity over strength-based programmes may be questionable in light of recent evidence (Lauersen et al., 2018). The superiority of strength-based IPPs is evident. However, as the mechanism of action differs from multimodal exercises, with the protective effects activating at different times and for different reasons. The implementation of superiority trials or three-armed trials is ideal for filling this gap in the research and has been successfully applied in football (Al Attar et al., 2017). The perfect study would test a strength-based NMT against a multimodal NMT and a sham IPP before multimodal IPPs are dismissed as inferior and the baby is thrown out with the bathwater.

2.8.2 Flexibility training

Flexibility is defined as any exercises used to increase range of motion and tissue extensibility, which regularly is described as stretching exercises (Brunner et al., 2019). Stretching can improve flexibility, but as there is no evidence of a causal relationship with injury reduction, the addition of stretches remains controversial (Brunner et al., 2019). The research into flexibility training to prevent injury is presently unpopular to undertake, and the existing studies on this subject are older than average of injury prevention studies.

McCrary et al. (2015) believe that dynamic stretching is possibly not detrimental to upper extremity performance, but static stretching is known to decrease performance. Stretching did not show any protective effect, and mainly static stretching showed no evidence for pre-or post-activity implementation to reduce injuries (Dijksma et al., 2020, Leppanen et al., 2014, McCrary et al., 2015). The knowledge that flexibility training does not have a preventative effect is well recognised in the research community and is widely accepted in the sporting world.

2.8.3 Balance and proprioception training

Postural exercise with the goal of enhancing joint stability and joint positioning sense, which can include balance devices or asymmetrical coordination exercises, describes balance and proprioception (Brunner et al., 2019, Lauersen et al., 2014). Studies investigating balance or proprioception training, and its ability to influence injury incidence have grown rapidly since the 1990s (McBain et al., 2012a). Leppanen et al. (2014) found that 80% of all programmes that produce a prophylactic effect included balance or coordination exercises.

Undoubtedly the most investigated neuromuscular intervention is balance board training, and shows a reduction in ankle injuries and lower extremity injuries in general, albeit with a strong presence of heterogeneity (Leppanen et al., 2014). The initial research on balance boards was where training equipment and training strategies met for the first time (Vriend et al., 2017). Proprioception training showed a beneficial effect on all injury reduction in one systematic review, but high levels of heterogeneity should proscribe taking the result at face value (Lauersen et al., 2014).

Although a combination of balance and strength training proved effective in adults, a subgroup analysis of balance exercises showed no benefit when included *versus* programmes that excluded the component in ACL IPPs (Brunner et al., 2019). Similarly, Sugimoto et al. (2015) reported that balance exercises might result in less protective effects when added to specific ACL injury prevention IPPs, which means that for structure-specific IPP, inclusion of balance training resulted in an poorer result than if included rather than when it was left out.

Hubscher et al. (2010) and Rossler et al. (2014) found that balance training may reduce lower extremity injuries in youth athletes. The performance of general IPPs has shown a small improvement in balance after concluding programmes in youth athletes (Faude et al., 2017). The neural system in youth athletes has not yet matured and can explain the increased benefit and effect found in comparison with adults.

McBain et al. (2012b) found some studies included upper extremity proprioception training, but as the programme design revolved around the lower extremity, but the programmes have been inadequately detailed and recorded. A limited amount of functional tests are validated to measure balance in the upper extremity, but the star excursion balance test initially developed for the lower extremity is gaining recognition (Cools et al., 2015).

In summary, balance training should be included for youth athletes and children as the benefit has been adequately proven. The inclusion of balance or proprioception exercises in IPPs for adults is questionable in its current format, as the best-case scenario is that it has no added benefit, but at worst it has detrimental effects on the rest of the programme or on the other exercise components.

2.8.4 Mobility training

Mobility is defined as exercises with the aim of moving through available range without the intent to increase range or to load the exercise to challenge strength or power. Activities that mobilise statically and dynamically can include agility training, where a quick change of direction is performed under control (Crossley et al., 2020). Mobility training is regularly confused with stretching exercises, but the main aim is to move a joint through full range of motion rather than to gain more range.

Agility exercises are rarely explicitly described in the literature and are possibly understudied. Huang et al. (2020) found that agility is a component present in successful ACL IPPs and advocate its use based on its inclusion in best practice guidelines. The overall effectiveness was only reviewed in one systematic review and is successful if combined with plyometric training (Brunner et al., 2019). Agility and mobility are the least included component in female footballers’ IPPs (Crossley et al., 2020).

Mobility work is a modern component that is included in warm-ups within various sports, with some incorporating traditional physiotherapy treatments like trigger-point release or accessory passive-joint mobilisations into an exercise. The research has yet to catch up to current practice as a gap exists in the literature regarding its use and effectivity. The current evidence shows it might help prevent ACL injuries but has not shown critical inclusion value.

2.8.5 Plyometric training

Plyometric training is defined as exercises with the primary aim to improve power, frequently consisting of ballistic and forceful movements like jumping or rebounding with optimisation of the stretch-shortening cycle (Brunner et al., 2019, Crossley et al., 2020, Taylor et al., 2015, Sugimoto et al., 2015). Plyometric training can induce power gains, but only if a stimulating load is reached.

The concept of enhancing power and its potential causal relationship to limit injuries has been progressively growing since 2000 (McBain et al., 2012a). The evidence reveals that increasing power through training is ineffective to prevent or reduce injury in adults (Brunner et al., 2019).

Meanwhile, jumping exercises proved to be particularly beneficial in reducing injuries in youth sport (Rossler et al., 2014). The authors acknowledge that the plyometric exercises correlate to lower extremity strength and power but chose the classification as a plyometric protocol. IPPs produce a slight performance enhancement effect in youth athletes in activities like running or sprinting (Faude et al., 2017), indicating an increase in physical qualities.

However, the inclusion of plyometric training proved to be no more beneficial to prevent ACL injuries in young females (Sugimoto et al., 2015). In contrast, Huang et al. (2020) purport that plyometrics should be included not based on specific sub-group analyses but on examining the components included in effective IPPs, which are confusing correlation for causation. The research does not find plyometric training by itself effective in adult IPPs.

2.8.6 Functional training

Functional exercises include non-specific exercises that can include aerobic exercises like sprinting or running (Brunner et al., 2019). Faude et al. (2017) found that IPPs performed in youth athletes result in a large increase in sprint performance and sport-specific physical testing. Functional training will stimulate many general physical capabilities that are typically used to measure the physical qualities of performance enhancement.

Technique coaching and specific landing stabilisation training have proven effective in preventing ACL injuries in young female athletes and is suspected to be a key component of success (Huang et al., 2020, Petushek et al., 2019). Graded and progressive running programmes showed no prophylactic effect in preventing novices' running injuries (Leppanen et al., 2014). However, functional training by and large shows no superior benefit when performing it exclusively and is practically unavoidable when performing any IPP.

2.8.7 Multimodal exercises

On the whole, most programmes consist of multimodal exercises (Faude et al., 2017, McBain et al., 2012a). Leppanen et al. (2014) state a predominant sentiment in the field where the multimodal exercises are theorised to bring about the whole outcome and are thought to be the sum of their parts. The search for superiority might then be unattainable as the active effect may lie in the interaction between exercise components and not the whole. Multimodal exercises are a combination of more than one training component, for example, strength and balance.

The majority of youth NMT consists of general multimodal exercises with some evidence purporting that a plyometric component may be more prophylactic (Emery et al., 2015b, Faude et al., 2017, Rossler et al., 2014). Multimodal IPPs for adults athletes effectively prevent injuries in the lower extremity, including the knee, ACL, and ankle but not in the groin (Brunner et al., 2019). Crossley et al. (2020) found low-level evidence that multimodal IPPs reduce all injuries by less than a third and ACL injuries by almost half in female footballers and found contrary to most other studies that multimodal exercises were superior to single exercise IPPs.

Multimodal IPPs showed a modest effect on all physical performance attributes except for endurances with sport-specific programmes superior to general programmes (Plummer et al., 2019). Multimodal exercises and IPPs may effectively prevent lower extremity injuries (Hubscher et al., 2010). Multimodal youth IPPs improve neuromuscular performance and reduce injury risk ,as physical performance enhances (Faude et al., 2017).

The hypothesis that multimodal exercises would elicit the most beneficial effects of each component may be inappropriate. Lauersen et al. (2014) warn that pooled evidence indicates the opposite and that extensive multi-component IPPs may not only reduce overall effectiveness, but compliance may suffer the more all-embracing exercises and programmes become. The effect of superiority may be sport or sex specific. While ideally, the most effective component should be the most considerable portion of an IPP, it is not so by intention but due to design. The research is not in agreement on multimodal exercise's superiority, only on the fact that it is the most voluminous (Faude et al., 2017, McBain et al., 2012a).

2.9 Mechanism of action for neuromuscular training

The research community has not adequately investigated the mechanisms of action for NMT. The research focuses more on achieving results than expanding on plausible mechanisms for the results or exploring the variables (Bekker and Clark, 2016). A disconnect exists when the intervention is described locally, but the adverse effect is global. Thus, the training exercises are described from segment level, i.e., the knee is strengthened, while athletic injuries are deemed to occur due to failure on a system level, i.e. the foot planted with knee collapse results in an ACL injury (Lauersen et al., 2018).

Irrespective of the uncertainty as to which level the mechanisms should target, the ambiguity is compounded as the investigations target different populations in various contexts. Participants include vulnerable sub-groups like youth athletes who lack tissue maturity resulting in anatomical and physiological differences that may have different mechanisms (Hanlon et al., 2020, Zaremski and Krabak, 2012). For youth and adult athletes there may be different and distinctive explanations of how NMT and IPP produce a prophylactic effect.

In simple terms, NMT has been shown to work, but how and what works remains unanswered. The lack of evidence of which measures are most related to real-world injury risk and rate decreases prevails (McBain et al., 2012b). Additional research is required to gain insight into how different exercise intervention components achieve their effects (Emery and Pasanen, 2019, Hubscher et al., 2010). The mechanisms for performance enhancement of sport-specific skill remain equally elusive as injury prevention, but it is theorised that improved neuromuscular control is involved (Faude et al., 2017).

The contemporary description of the mechanism is generically explained to involve neuromuscular control or activation. In a similar vein, exercise intervention can generate neuromuscular adaptations (McBain et al., 2012b). The literature has attempted to further define this enhanced neuromuscular control or adaptation. NMT is proposed to enhance reflexes, stability, and proprioception (Leppanen et al., 2014). They are consequently attributing the effect of NMT to the improvement of physical attributes in the form of circular arguments, blurring the line between performance enhancement mechanisms and injury prevention mechanisms.

In juxtaposition with the enhancement theory is the deficit or imbalance model. It has been suggested that certain intrinsic risk factors may be modifiable such as strength or balance deficits, and can be targeted by whole-body or specific IPPs (Hanlon et al., 2020). The risk factors are suspected to be minimised or eliminated by engaging in NMT, nevertheless, this is rarely pursued. Despite showing the reduction in the incidence of injury in football players conclusively (Al Attar and Alshehri, 2019a, Crossley et al., 2020, Owoeye et al., 2020), it is uncertain what intrinsic risk factors were addressed to account for the injury reduction effect (Hanlon et al., 2020).

The prevailing solution seems to be a combination of both performance enhancement and risk factor minimisation. Interestingly, even though no causal link between performance attributes, risk factor minimisation and injury prevention have been found, the prevailing solution may well rest on a combination of these variables. Faude et al. (2017) hypothesised that injury prevention is a combination of performance parameter enhancement and associated risk factor minimisation facilitated by the performance of warm-up protocols. The statement above is substantiated by insights gained from balance training which can improve postural control and display enhancement in both static and dynamic balance as a result of possible improvement in neuromuscular control, which may account for the incidence reduction (Leppanen et al., 2014).

The literature base is weak for NMT's mechanism of action as a whole, yet strength as a component of NMT has recently been more thoroughly addressed. According to Lauersen et al. (2018), strength training is theorised to reduce and prevent acute injury through direct and indirect mechanisms. The direct mechanism is the straightforward improvement of muscular force production of the prevention area. The indirect mechanism of strengthening is hypothesised to occur through co-ordination enhancement, vulnerable tissue de-loading, improved technique, and adjusted risk-assessment perception.

Overuse injuries, as opposed to acute injuries, have different triggers that cause the event and are suspected of having different mechanisms that prevent injury. McBain et al. (2012b) describe the engagement in preventative exercises as a way to bring absorbed forces and applied forces into equilibrium. A risk factor for injury, if present, coupled with an imbalance of forces can further strain a tissue, which can result in injury due to accumulative overload. For example, dynamic knee valgus can overload the medial knee structures, where the injury prevention exercises are selected to decrease dynamic knee valgus, thus unloading the overstressed tissue (Lewis et al., 2018, Bittencourt et al., 2012).

Elaborating on preventing overuse injuries by strength exercise, Lauersen et al. (2018) suggest that enhancement of fitness levels, load adjustment training, gradual tissue adaptation, together with the carry-over benefits that protect from acute injury are responsible for preventing overuse injuries. The attention that the preventative mechanisms have received is disappointing. The gaps in the literature are large and numerous, with a myriad of factors not yet addressed. Fatigue is one of the factors that only recently has appeared in the literature. Fatigue has become an interesting addition to the injury prevention dilemma, as performance can be affected by muscle fatigue and delayed neuromuscular activation (Hanlon et al., 2020). Thus, it is evident that NMT works, not how or why it works, and the question as to when it starts to work has not been addressed yet.

The evidence base investigating NMT and its mechanisms comprises of explanations for outcomes, which are measured only after an extended performance, of up to nine months (Lauersen et al., 2018). The immediate or daily effects that NMT can potentially produce and its effects on injury prevention have up to this point not been discussed. Intra-session changes in the motor patterns of exercises during testing and rehabilitation are regularly apparent when observed. After a prolonged intervention, alteration of motor patterns is accepted favourably, but immediate changes are viewed with scepticism. The immediate variability in movement performance is frequently ignored as the existence and quantification of the suspected enhancement is challenging to confirm, prove and document by means of subjective visual observation.

Measuring after performing single session interventions can produce a different instantaneous result which is the prerogative of a neuro-muscular approach (Barbosa et al., 2013, Moon et al., 2014, Tsao and Hodges, 2007). The neuro-muscular approach is the cornerstone of NMT and moves away from reductionism to an emergentist view of function and movement. The positive results demonstrated by applying landing stability training to promote effective landing mechanic, by utilising feedback is testament to the neuromuscular approach's direct modulation. Acute improvement has been documented within a single jump landing feedback session (Petushek et al., 2019).

Tsao and Hodges (2007) reported a single session of isolated transverse abdominis training resulted in earlier recruitment of the transverse abdominis, thus displaying enhancement in feedforward postural control. Barbosa et al. (2013) found a Pilates centring technique of the abdominals allowed for an instantaneous higher level of activation of the biceps brachii and resulted in higher EMG data. The authors proposed that this was due to a possible firing rate modulation. Moon et al. (2014) reported that performing short-foot exercises improved the dynamic balance of individuals with excessively pronated feet immediately. NMT mechanisms need to be examined not only after the result has been achieved or not, but also during the performance to assist and enhance clarity on how the mechanisms work.

A hypothesis is that the variability may be observable changes of outputs (muscle strength and function) due to input alteration/adaptation *via* an increased neural drive by the nervous system. Petushek et al. (2019) propose that NMT can influence and manipulate muscle activation and muscle imbalances, even when considering that those mechanisms fluctuate daily. The hypothesis demonstrates Bittencourt et al. (2016) complex system in action, where a recursive loop can make changes to the identified risk factor during the task performance and bring about an immediate observable change as the system uses both a feed-forward and feedback loop.

The overarching resolution points to the need to amalgamate a complex system approach to investigate the preventative mechanisms of NMT. A complex system can consider both short-term and long-term mechanisms and their potential non-linear interaction with each other. Several proposed preventative mechanisms are insufficient to explain the result individually while imprecise in combinations. The literature provides a keyhole view on this topic which requires much more rigorous academic investigation to provide an emergent view.

2.10 Conclusion of the literature review

Injury prevention research is a continually evolving field with many intricacies and obstacles to overcome in order to uncover precise and accurate findings. Researchers should be aware of the complexities in defining, measuring and recording injuries. Consensus statements, aetiological guidelines, conference papers and multi-disciplinary experts should be consulted at the protocol design phase. Study designs should match research aims and introduce new approaches to improve data analysis and synthesis. The field requires careful attention not to the magnitude of the results but as to how the results were obtained in order to raise evidence quality.

The literature provides an overwhelming consensus regarding the fact that exercise intervention can prevent injuries overall and lower extremity injuries specifically. Lack of evidence precludes extrapolation on the prophylactic effect for upper extremity and overuse injuries in general. The injuries cannot be predicted, but they can be prevented. The mechanism on how and when the effects can be achieved remains elusive. Currently, the NMT components of strength and multimodal exercises show the most promise.

CHAPTER 3 - METHODOLOGY

3.1 Type of Study

The dissertation consists of a systematic review of effectiveness with a meta-analysis (Tufanaru et al., 2020). According to the Joanna Briggs Institute (JBI) level of evidence for effectiveness, the level of evidence produced is Level 1.a – Systematic review of RCTs.

3.2 General Methodology

The systematic review and meta-analysis utilised the methodology set out by the JBI Reviewer's Manual for JBI Systematic Reviews of Effectiveness (Tufanaru et al., 2020) and the guidelines proposed by the PRISMA statement (Moher et al., 2015). A systematic review is a method used to minimise bias in reviewing the literature by using a pre-planned design (Cheung and Vijayakumar, 2016).

The research question was designed based on the utilisation of the Population Problem, Intervention, Comparison or Control, and Outcome (PICO) methodology (Eriksen and Frandsen, 2018). The eligibility criteria are described and reported for both study and report characteristics. The articles were organised using the reference management software package, EndNote X9.3 (Clarivate Analytics, PA, USA). No similar prospective systematic reviews have been registered with the Cochrane Library (Wiley), JBI Evidence Synthesis, and PROSPERO as of July 2020.

A priori registration of the systematic review protocol is fully and freely accessible with PROSPERO (CRD42020204141). Protocol registration is recommended to limit *post hoc* decision making, selective outcome reporting, reduce publication bias and improve general transparency in systematic reporting (Liberati et al., 2009). Amendments have been made, and the exact reasons were provided for the changes. The study protocol has been accepted for publication in the *JBI Evidence Synthesis*.

3.3 Inclusion criteria

3.3.1 Types of participants

This systematic review considered relevant studies that included human athletes participating in all forms of sport, irrespective of sex, age, ethnicity, setting, geographical location, or level of skill. Study participants were generally healthy and free of injury at the start of injury prevention studies. However, to investigate acute *versus* overuse data, the inclusion of both injured and uninjured participants is necessary.

Subsequent or recurring injuries occur regularly in athletes with pre-existing overuse injuries; these athletes partake in prevention strategies to prevent secondary injuries. Non-self-propelled or vehicle assisted sports were excluded due to the high levels of damage sustained from collisions that have no bearing on the biomechanical and neuromuscular adaptations that exercise intervention is purported to facilitate and is a proposed mechanism whereby potential injuries are reduced.

According to PubMed's medical subject headings (MeSH), Sport was defined: "Activities or games, usually involving physical effort or skill. Reasons for engagement in sports include pleasure, competition, or financial reward (NCBI, 1988 para. 5)." As athletes compete in sport, the definition provided absolute clarity when the definition of sport was ambiguous. A summary definition from Bahr et al. (2020) is presented for an athlete: An athlete must train to improve performance and results; participate actively in competitions while formally registered, and spend a considerable amount of time on the endeavour.

The sport was deemed upper extremity dominant if upper extremity function is required for the bulk of the sport-specific skills, such as volleyball, tennis, and handball. The sports such as football, rugby, and sprinting are classified as lower extremity dominant sports as these sporting codes utilise the lower extremity for most sport-specific skills.

3.3.2 Types of interventions

The study considered literature that assesses all exercise interventions' effectiveness to prevent or diminish the incidence of injury to the shoulder. All types of exercise intervention were included and grouped primarily into seven categories, i.e., strength training, flexibility training, balance and proprioception training, mobility training, plyometric training, or multimodal exercises.

Exercise intervention was included if it conformed and corresponded to the definition of exercise. Exercise is defined by Winter and Fowler (2009 p.459) as: "a potential disruption to homeostasis by muscle activity that is either exclusively, or in combination, concentric, eccentric or isometric." Exercises interventions include bodily activity meant to improve health and physical attributes. The definition of each specific component is stated in Chapter 2.8 individually.

3.3.3 Types of comparators

Studies that compare the intervention to either a pure passive control group receiving no interventions (regular training, usual practice or no additional training) or an active control arm receiving alternate forms of intervention, e.g., other programmes, technique feedback, supplementation, equipment, or assistive devices were included.

3.3.4 Types of outcomes

The primary outcome measure of interest is the number of shoulder injuries or pain, as defined in each study. In lieu of shoulder injury incidence, upper extremity incidence was extracted. The outcome variables encompass injury incidence or the number of acute and overuse injuries. The outcome is dichotomous in nature as an injury event has occurred or not, losing some of the granularity of categorical data but allows for extensive correlation (Nielsen et al., 2020b).

The shoulder area includes injuries to the rotator cuff, clavicle, scapula, and proximal biceps tendon (Bahr et al., 2020). In circumstances where the injury definition is ambiguous, this study defined an injury as per the definition of the International Olympic Committee's consensus statement (Bahr et al., 2020 p. 374): "Injury is tissue damage or other derangement of normal physical function due to participation in sports, resulting from [the] rapid or repetitive transfer of kinetic energy."

The number of injuries or injury incidence was calculated using incidence data, RR, odds ratios (OR), rate ratios (rr), injury incidence rate (IIR) and injury rate ratio (IRR) reported in the studies or based on raw data provided in the included studies (Hopkins et al., 2007). Research in injury prevention reports injuries in an upper and lower extremity split or specific anatomical locations, both were evaluated and relevant data extracted. No limit was placed on the minimum length of follow-up to investigate both short-term and long-term effectiveness.

The incidence is the number of new injury events that were sustained in a specific period within the population investigated, while prevalence denotes the existing number of injuries divided by the whole population at any given point in time (Bahr et al., 2020). Research studies measuring acute injuries predominately use incidence compared to studies that investigate overuse injuries which preferred prevalence. This systematic review used the number of injury events or calculated the events from the existing data to compare both acute and overuse focused studies.

The first secondary outcome was to provide acute *versus* overuse data (according to each study's definition) estimates. The second was to describe and categorise the different types of exercise intervention found in the IPPs, i.e., strength training, flexibility training, balance and proprioception training, mobility training, plyometric training, or multimodal exercises.

The third was to describe and categorise the intervention programmes' components of shoulder specific exercises into a closed or open kinematic chain. The goal of categorising the kinetic chain was to establish an overview of current prevention programmes for the sporting shoulder. Unclear reporting of interventions in eligible studies was investigated further by examining referenced material or supplementary documentation.

3.3.5 Types of studies

Prospective RCTs and cluster RCTs evaluating the effectiveness of exercise intervention to prevent injuries were considered for inclusion. No restriction on language or publication status were applied and included a search for literature from database inception until September 2020. Unpublished studies were not excluded to minimise and prevent publication bias. Abstracts without available full-text manuscripts were omitted as the critical appraisal of the methodological quality would be impossible.

RCTs provide persuasive proof that an identified and presumed risk factor is causally linked; and represent the differences between interventions during the surveillance period (Hopkins et al., 2007). The emphasis on RCTs is a recognised methodology preferred by the Cochrane Collaboration (Tufanaru et al., 2015). Inclusion of non-randomised studies with a high risk of bias will compound and not minimise the bias resulting in potentially distorted results; exclusion of non-randomised evidence is endorsed and recognised in the literature (Huang et al., 2020, Weir et al., 2016).

Cluster RCTs are commonly used in exercise intervention studies as contamination can be significant and individual randomisation is at times impractical (Emery, 2007). Cluster studies apply the intervention at a team level but measure outcomes like injury incidence at the individual player level (Huang et al., 2020). A cluster RCT allows for multi-location interventions covering larger geographical areas and consists of larger sample sizes.

High-quality RCTs measuring a final clinical end-points, i.e. injury prevention, are regarded as the gold standard for effectiveness studies in health care (Mitchell et al., 2020). RCTs measuring intermediary or surrogate clinical outcomes, i.e. shoulder strength, were excluded (Brignardello-Petersen et al., 2015). Surrogate outcome measure cannot be causally linked to a reduced injury incidence unless specifically investigated.

Quasi-experimental studies and observational studies were not included as enough RCTs were identified on the subject matter to prioritise RCTs, an approach favoured by the JBI (Tufanaru et al., 2015). Including only RCTs reduces the selection bias and sample errors inherent in non-randomised study designs and is not recommended to be combined with RCT (Emery et al., 2015b).

3.4 Search strategy

The principal researcher developed the search strategy, and the strategy was peer-reviewed. A three-step sequential strategy was utilised to discover relevant studies. The search process was designed and implemented to uncover published and unpublished studies. Firstly, a restricted investigative search on MEDLINE (PubMed) was performed using the keywords “shoulder injury”, “primary prevention”, and “exercise intervention”. The initial search allowed for the investigation into text words that compromise the title, abstract, and index terms to develop a comprehensive search strategy for MEDLINE (PubMed).

The literature search included both MeSH terms and text words. Search terms from similar reviews were screened to determine the strategy's completeness (Lauersen et al., 2014, Lauersen et al., 2018). The second search was expansive and employed all the identified keywords and index terms contained in the fully developed search strategy with the adaptations required by each specific database. The search strategy and the search results for each database are attached (Appendix A).

Thirdly, backward citation tracking was implemented by manually screening all eligible articles' bibliographies to identify any research overlooked by the electronic search. Forward citation tracking implementation of the included articles was done by utilising ISI Web of Science. Two researchers searched the databases independently with the search strategy.

All databases were searched from inception until September 2020, with an updated search performed in December 2020. No language restriction was applied, and the results were filtered to “Human” populations for RCTs. All studies that complied with the inclusion criteria from excluded reviews, systematic reviews and meta-analyses were included from the screening of their reference lists (Asker et al., 2018, Lauersen et al., 2014, Lauersen et al., 2018).

3.4.1 Information sources

The ten databases that were searched from inception until 2020 include: Cumulative Index to Nursing and Allied Health Literature (CINAHL) complete (EBSCOhost); Cochrane Central Register of Controlled Trials (Wiley); MEDLINE (PubMed); Physiotherapy Evidence Database (PEDro); ProQuest Health & Medical Complete and Nursing & Allied Health Source (ProQuest complete); ScienceDirect (Elsevier); Scopus (Elsevier); SPORTDiscus (EBSCOhost); and Web of Sciences (Clarivate Analytics). Sources of unpublished studies and grey literature were searched for using Academic Search Ultimate (EBSCOhost) and MasterFILE Premier (EBSCOhost).

3.5 Study selection

The completed search results were transposed and arranged in Microsoft Excel (Redmond, WA). All identified citations were collated and uploaded into EndNote X9.3 (Clarivate Analytics, PA, USA), enabling removal of duplicates using the referencing software’s automatic algorithms. Manual checking and removal of duplicates were performed for studies not identified as redundant by the software. The two reviewers performed a familiarisation procedure on an unconnected sample to confirm that the selection process was performed sufficiently.

A three-step selection process of studies was conducted independently by two reviewers. The titles were screened for relevance, followed by abstract screening and, ultimately if found eligible, a full-text review. Studies were rejected if the title had no apparent relationship with injury prevention interventions. Abstracts were assessed if uncertainty existed after title screening. Eligible studies were retrieved in full, and the entire manuscript was assessed for inclusion against the inclusion criteria. In cases where the abstract did not conclusively confirm eligibility, the full-texts were retrieved for review.

All studies were in English, except for one abstract (Fer et al., 2017), which was translated using Google Translate. The article did not require other professional translation as the study was not eligible for inclusion. The included studies' citations were imported into the JBI's System for the Unified Management, Assessment and Review of Information (SUMARI) software (Joanna Briggs Institute, Adelaide, Australia) for processing (Munn et al., 2019).

Reasons for the exclusion of full-text studies were recorded and reported in the systematic review. All disagreements that arose between the reviewers during the study selection process were resolved by means of discussion. The process revealed a high interrater agreement and did not require recourse to the third reviewer. The search results are reported in whole and visually represented as specified by Moher et al. (2015) in a PRISMA flow diagram.

3.6 Assessment of methodological quality

Two independent reviewers evaluated the internal validity of the studies to determine the individual risk of bias. The methodological quality was assessed after the inclusion of the eligible studies. The standardised JBI Critical Appraisal Checklist for Randomized Controlled Trials, consisting of 13 questions, was utilised (Appendix B). A pilot assessment was done to determine the interrater agreement on several unrelated studies and calibrate the assessment process. No circumstances arose where differences in quality ratings between the reviewers could not be resolved after discussion. No arbitration by the third reviewer was required as consensus was reached on all points.

The results of the critical appraisal are reported in a narrative form and a table. All studies, regardless of the results of their methodological quality, underwent data extraction and synthesis. The risk of bias is addressed post inclusion in the presentation of the results, and the potential influence on the findings are explained (Tufanaru et al., 2015).

3.7 Data extraction

Two reviewers performed the data extraction independently, utilising a modified data extraction tool from the JBI-SUMARI software. The JBI data extraction instrument was modified to include the following data points: First Author’s last name; Publication year; Critical appraisal rating; Country; Setting (sport, level); Participants (sex, age); Sample (sample size, declined to participate, drop-out rate, the sample analysed, intention-to-treat or per-protocol analysis, cluster adjustment); Intervention (name or description, intervention type, frequency, dose, compliance, categorisation, open *versus* closed kinetic chain shoulder exercises); Outcome measures (shoulder or upper extremity, number of injuries in the intervention *versus* the control group, acute *versus* overuse injuries, primary outcome); Bias and main limitations.

The template was piloted on an unrelated sample and was found serviceable. The retrieved data comprised the specifics in the study relating to population demographics, type of intervention and characteristics, primary and secondary outcome measures, and the critical appraisal rating (Appendix C). A double-entry method was utilised with data extraction to reduce errors. The juxtaposition of sample sizes and authors was used to avoid extraction from duplicate publications.

No disagreements arose between the reviewers in the data extraction proses, and inter-rater agreement was high. An email was sent to the corresponding author of studies with missing data, incomplete data, or if clarification of ambiguous data was required. E-mails were sent to seven authors for further information. Five authors responded, while two did not respond to the correspondence. From the responses, two authors provided full texts articles, and one provided the raw data requested. The remaining authors could not provide the raw data as it was either not available, not yet published, or embargoed.

3.8 Ethical considerations

A systematic review of the literature requires no human participation. The principal researcher applied for an ethical clearance waiver with the University of the Witwatersrand's Human Research Ethics Committee. However, waivers are no longer necessary for systematic reviews as per the University's policy. The research produced no conflict of interest and did not receive any external funding.

3.9 Data synthesis

The synthesis aims to pool quantitative data for a statistical meta-analysis employing, the JBI-SUMARI software. A narrative method was utilised, where data does not permit pooling, and the findings are tabulated. The primary outcome used was the number of injuries, and the number of individuals in the control and experimental groups. Estimates of injury incidence derived from simple counts of injury events in the experimental and control groups are an acceptable method to synthesise data but require more in-depth analysis to adjust and identify other risk factors (Hopkins et al., 2007).

Effect sizes for dichotomous data were reported as RR, and no continuous data was extracted. RR is also known as risk ratios and is intuitive to interpret for a layperson, while ORs may sometimes be difficult to interpret and can sometimes be confusing (Hopkins et al., 2007, Tufanaru et al., 2015). The confidence intervals (Cis) were calculated at 95% for all analyses of the effect sizes. A quantitative synthesis was performed by meta-analysis.

A double data entry method was used to prevent methodological errors. A funnel plot was performed in STATA 16 (StataCorp, College Station, USA) to assess publication bias and tested for funnel plot asymmetry. The funnel plot was tested with a trim and fill method to determine statistically the number of studies missed during collation. Publication bias was further formally tested for small-study effects using the Egger, Begg, and Harbord statistical tests.

The recommendation to adjust for the non-independence of data in cluster RCTs was followed by utilising a random effect statistical model to account for the clustering effect (Nielsen et al., 2020b). The number of injury events is on an individual level and not on cluster level, discouraging further cluster adjustments (Emery, 2007). The prospected studies were theorised to be homogeneous enough to pool data and conduct a meta-analysis without performing further statistical adjustments. The number of injury events is not influenced by the different types of study designs or methods of analyses, but the sample sizes can be affected.

Nevertheless, the broad topic covering many different sports was hypothesised to achieve higher heterogeneity levels from either a clinical or methodological perspective that would require further sub-group analysis (Higgins et al., 2003). Heterogeneity is the genuine discrepancy in the outcomes related to the included studies' internal factors, excluding random sampling errors inherent in all studies (Barili et al., 2018). The statistical test used to identify heterogeneity seems redundant as the likelihood of its presence is high, and the core concern is quantifying to what extend it influenced the results (Higgins et al., 2003).

The ultimate aim is not only to produce a mean effect size but also to establish how this is distributed around the mean to give an accurate reflection of the true effect (Borenstein et al., 2017, Mogharnasi et al., 2019). The results' robustness requires judicious investigation by examining different methodological choices in the sensitivity analyses (Barili et al., 2018). The exclusion of non-randomised studies could have induced publication bias, but low-quality methodological studies' omission is acceptable in the literature (Faude et al., 2017). The results are interpreted from a statistical, practical, and clinical significance perspective (Tufanaru et al., 2015).

3.10 Meta-analysis

A meta-analysis was performed to increase the statistical power to enable the identification and quantification of the treatment effect to prevent injury and allow generalisation of the results (Tufanaru et al., 2015). The statistical synthesis produced by a meta-analysis enables the compilation of a large portion of research and is the preferred method in several fields to determine the magnitude of an effect across the available evidence (Barili et al., 2018, Cheung and Vijayakumar, 2016).

A meta-analysis provides a preliminary departure point to establish clinical guidelines (Melsen et al., 2014) and is regularly used as a benchmark for an outcome. The meta-analysis intended to infer the outcome beyond the selected studies, and thus a random-effects model was appropriate. Low likelihood existed that genuine homogeneity is present in the included studies due to their diversity of sports and populations (Tufanaru et al., 2015). Similarly, as heterogeneity was expected in the included studies due to differing designs, the choice of a random-effects model's was prudent (Barili et al., 2018).

The RR was used to provide an estimated summary effect during synthesis across the included studies. A summary effect is the average investigated outcome that is weighted and the designator of the effect size (Barili et al., 2018). The Mantel-Haenszel statistical method was utilised in order to determine effect size. In studies with smaller samples or fewer events, it is preferred over the inverse variance method, and as such is the method of choice when interstudy sample sizes are small (Tufanaru et al., 2020). The pre-planned decision was evaluated for adequacy during the sensitivity testing.

The Cochran's Q statistic and its *P*-value, together with the Chi-square, were used to identify statistical heterogeneity. These statistical testing procedures are conducted as part of a standardised testing procedure but are known to be a poor indication of genuine heterogeneity (Higgins et al., 2003, Melsen et al., 2014). These statistical tests are used to determine whether the effect sizes are homogeneous (Barili et al., 2018). A *P* value of less than 0.1 indicates significant heterogeneity as the statistical tests have low power and tend to be significant if a greater number of studies are included (Cheung and Vijayakumar, 2016, Fletcher, 2007, Higgins et al., 2003).

The I^2 statistic measures and quantifies statistical heterogeneity proportionally without identifying the amount of variance in the effect size (Borenstein et al., 2017). The statistic is descriptive and measures inconsistency amongst the included studies' outcomes, whilst not being affected by the number of studies included (Barili et al., 2018). However, the I^2 is a relative measure inversely related to the sampling error, while the Tau squared (T^2) is theoretically unaffected by sampling error and thus an absolute measure (Cheung and Vijayakumar, 2016). T^2 is an estimation of the actual effect variance and will be reported alongside the I^2 (Borenstein et al., 2017). The I^2 and T^2 statistical tests quantified the amount of heterogeneity present.

Higgins et al. (2003) propose the widely cited inconsistency cut-offs for I^2 as low (25%), intermediate (50%), and high (75%). The thresholds are criticised for being unrefined, and an accurate assessment in context should overcome the proposed cut-offs (Barili et al., 2018). The thresholds give no insight into the variance of effects. I^2 reports the interaction between two factors in the sample, while T^2 indicates a distinct factor in the study sample (Borenstein et al., 2017). The Cochrane collaboration has proposed ranges to represent inconsistency as follows: unimportant (0% to 40%), moderate (30% to 60%), substantial (50% to 90%), and considerable (75% to 100%) heterogeneity (Deeks et al., 2020, Huang et al., 2020). The heterogeneity needs to be assessed in light of statistical significance and quantitative significance contemporaneously.

The question to be addressed is not whether heterogeneity is present in a meta-analysis; instead, it is to discern the extent to which heterogeneity is present and determine the latter's impact on the true effect, as it exists in almost all meta-analyses (Melsen et al., 2014). The included studies are conceptually comparable enough to justify a meta-analysis. However, despite analysis with a random-effects model, the amount of heterogeneity was expected to require subgroup analysis to determine the impact on the outcomes (Tufanaru et al., 2015).

The subgroup performed were to explore clinical and methodological heterogeneity; it was hypothesised that methodological heterogeneity would be the most significant contributor to the variability. The *a priori* subgroup analyses were further prespecified to examine and provide a comparison of effects in shoulder injuries *versus* upper extremity injuries, acute *versus* overuse shoulder injuries, shoulder specific versus non-specific programmes, upper *versus* lower extremity dominant sports, and RCTs *versus* cluster RCTs. Shoulder specific programmes were programmes stated in the relevant study to target the area, or if at least four of the exercises included directly targeted the shoulder.

A pre-planned sensitivity analysis was performed to investigate the effect of differences that study design, statistical methods, and methodology had on the results. Sensitivity analyses were executed to assess decisions regarding the inclusion of different cluster adjustments methods; utilising different statistical models in synthesis performance, methods, and effect measures; and testing the inclusion of different methodological levels of quality. The testing ascertained if similarity existed regarding the effect magnitude and direction (Thabane et al., 2013).

3.11 Conclusion of the methodology

The chapter contained a detailed description of the method applied to perform the systematic review and meta-analysis. Transparent reporting according to recognised guidelines, like the PRISMA statement, ensures academic rigour and re-reproducibility. The next chapter presents the results obtained by performing a review and meta-analysis.

CHAPTER 4 - RESULTS

4.1 Study selection

The systematic search strategy retrieved 4191 potential studies, and a further seven studies were retrieved from other systematic reviews. Duplicate records were removed, resulting in the elimination of 2878 duplicates. Subsequent vetting using the title and abstract method excluded 2845 studies for not matching the inclusion criteria. Full-text manuscripts were retrieved for 26 studies due to possible compliance with the inclusion criteria based on the title and abstract. Manual searches of excluded reviews included studies' bibliographies and other meta-analyses' reference lists which uncovered another seven potentially eligible studies. A final full-text assessment dismissed 11 studies as ineligible and was removed with reasons (Appendix D).

The ultimate number of eligible studies included in the systematic review was 15 studies. The meta-analyses included all 15 studies between the primary and secondary analyses, where both included 13 studies each. The inter-rating agreement in the selection process was high as inclusion consensus was reached for all studies without recourse to the third reviewer. The process is visually depicted in Figure 4.1 below in the PRISMA flow diagram recommended by the methodological consensus statements (Liberati et al., 2009, Tufanaru et al., 2020).

4.2 Assessment of methodological quality

All included studies were critically appraised as per the protocol, and none were discarded based on low methodological quality. Removal before inclusion can result in selective inclusion, which can lead to potential biases. A critical assessment of included studies was performed utilising the standardised JBI Critical Appraisal Checklist for Randomized Controlled Trials. All included studies were either RCTs or cluster RCTs, enabling the use of only a single risk of bias tool without recourse to the JBI Critical Appraisal Checklist for Quasi-Experimental Studies (non-randomised experimental studies).

The methodological quality ranged from low to high, with an overall quality rate of moderate (55% range of 15.39 to 92.30%), as shown in Table 4.1. Thirteen questions were answered with either a yes, no or uncertain. Uncertain was used if the study lacked sufficient information to justify definitively in the positive or negative. The questions can be accessed in Appendix B.

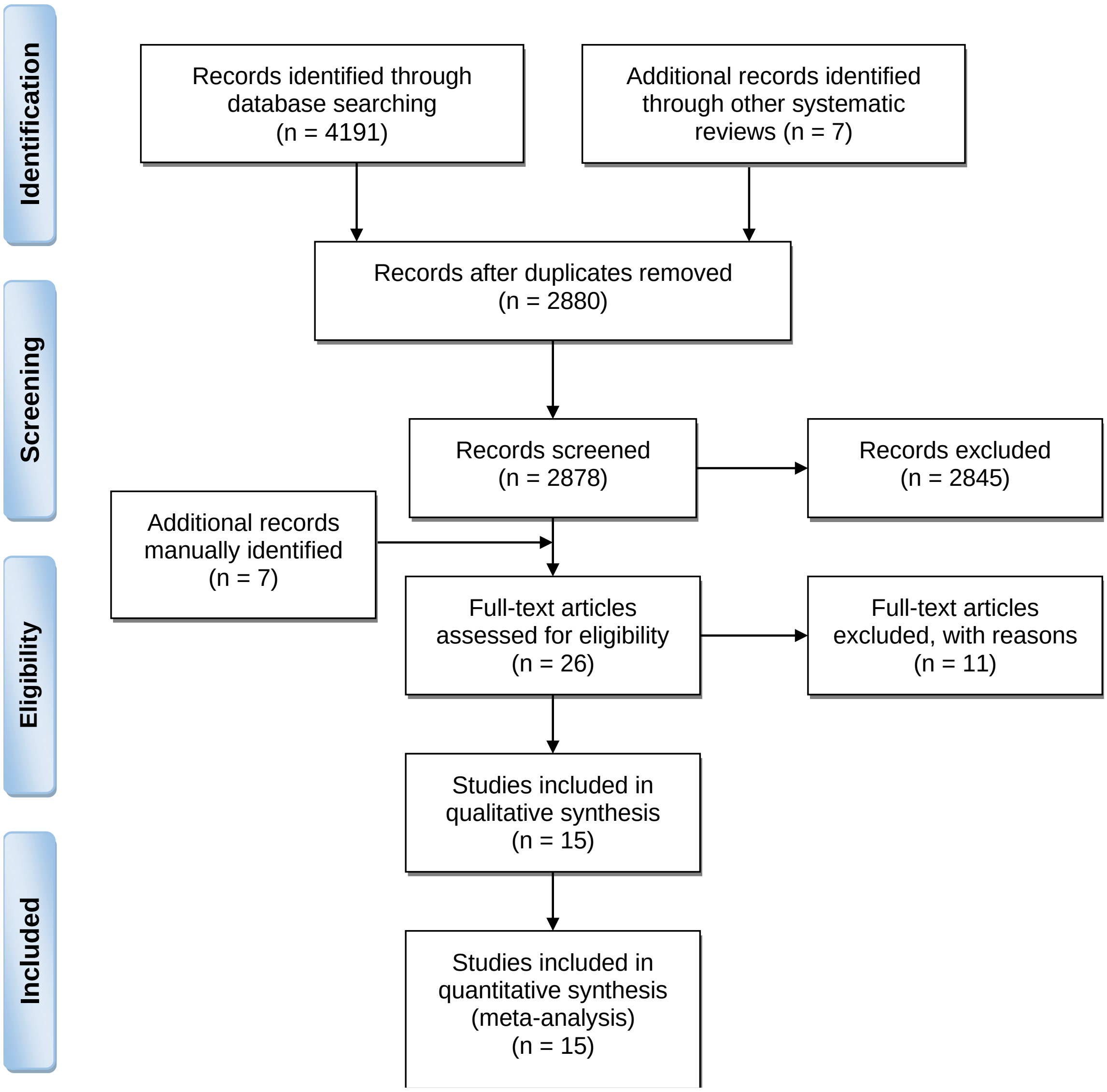


Figure 4.1: PRISMA study selection flow chart provided by Moher et al. (2015)

Studies that do not fully disclose the methods used to perform fundamental processes such as randomisation or allocation concealment may unintentionally or intentionally prevent full assessment and study replication. Researchers who do not fully disclose their processes cannot be deemed to have performed them correctly and are thus assigned an unclear designation.

True randomisation and disclosure of the procedure were adequately performed in 50% of the studies. Correct allocation concealment was performed and disclosed by 71.42% of the researchers. The baselines between the experimental and control group were similar for 78.57%. Participant blinding was achieved in 28.57% of included studies, with blinding of the delivery agent in 14.28% and the blinding of outcome assessors in 57.14%. The groups received the same intervention and then identical further treatment or support for14.28% of the time.

Table 4.1: Critical appraisal of the methodological quality

Study	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q 10**	**Q 11**	**Q 12**	**Q 13**	**%**
Al attar 2017	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	92.30
Andersson 2017	Y	Y	Y	N	N	N	N	Y	U	Y	Y	Y	Y	61.54
Attwood 2017	U	U	Y	Y	Y	U	U	U	Y	Y	Y	Y	U	53.84
Finch 2016	Y	Y	U	Y	U	Y	U	Y	Y	Y	Y	Y	Y	76.92
Hislop 2017	U	Y	Y	Y	N	N	U	Y	Y	Y	Y	Y	Y	69.23
Olsen 2005	U	Y	Y	N	N	Y	U	Y	Y	Y	Y	Y	Y	69.23
Osteras 2015	U	U	Y	U	U	U	U	N	U	Y	U	U	U	15.39
Pas 2020	Y	Y	Y	N	N	Y	U	U	Y	Y	Y	Y	U	61.54
Rössler 2018	Y	Y	Y	N	N	Y	Y	U	U	Y	Y	Y	Y	69.23
Sakata 2019	U	Y	Y	N	N	Y	U	Y	Y	Y	Y	Y	Y	69.23
Silvers-Granelli 2015	Y	U	Y	N	N	Y	U	U	U	Y	Y	U	Y	46.15
Sommervold 2017	Y	Y	U	N	N	U	N	Y	U	Y	N	Y	Y	46.15
Steffen 2008	U	Y	Y	N	N	Y	U	U	Y	Y	Y	Y	U	53.84
Verhagen 2004	U	U	Y	N	N	U	Y	Y	Y	Y	U	U	U	38.46
Wedderkopp 1999	U	U	U	N	N	N	U	N	U	Y	Y	U	U	15.39
TOTAL %	50.00	71.42	78.57	28.57	14.28	57.14	14.28	57.14	64.28	100.00	85.71	78.57	64.28	**55.90**

Y - Yes; N - No; U – Unclear
Questions listed in Appendix B

Follow up was completed sufficiently in 57.14% of studies, which then further described group differences and provided analyses with reasons. In 64.28% of the articles, the participants were analysed in their assigned treatment group. All eligible studies (100%) measured the outcomes in the same way for both groups. The outcomes were reliably measured by 85.71% of studies. The proper statistical method to analyse the data was used 78.57% of the time. The research was designed correctly to address the subject, with deviations accounted for in 64.28% of the studies.

4.3 Study Characteristics

The complete extracted data can be found in table format in Appendix E.

4.3.1 General design

Five studies were conducted in Norway (Andersson et al., 2017, Olsen et al., 2005, Osteras et al., 2015, Sommervold and Osteras, 2017, Steffen et al., 2008), two in Australia (Al Attar et al., 2017, Finch et al., 2016), two in the Netherlands (Pas et al., 2020, Verhagen et al., 2004), two in the United Kingdom (Attwood et al., 2017, Hislop et al., 2017), one in Denmark (Wedderkopp et al., 1999), one in Japan (Sakata et al., 2019), one in the United States of America (Silvers-Granelli et al., 2015) and one multi-country study was performed in Switzerland, Germany, the Czech Republic and the Netherlands (Rossler et al., 2018). The information is visually depicted in Figure 4.2.

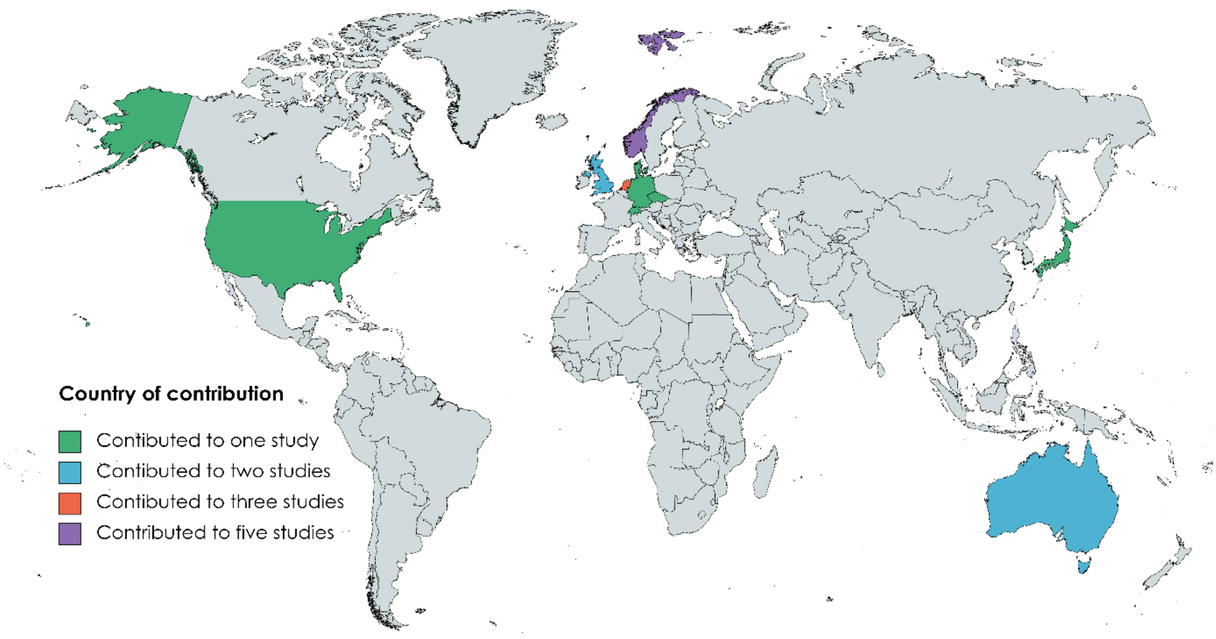


Figure 4.2: World map - Studies contributed per country

Europe was the principal contributor, with 73% of the studies hailing from the continent. The studies included were almost equally divided regarding study design, with eight cluster RCTs included *versus* seven RCTs. All included studies were published in the post-2000s with the single exception of Wedderkopp et al. (1999). A third of the studies was published in 2017, and more than half of the included studies was conducted between 2017 and the present. All included studies were published in English and therefore no translation was required.

4.3.2 Demographics

Seven different sporting codes were investigated. The upper extremity dominant sports, which are sports where the upper extremity function is required for the bulk of the sport-specific skills, included handball (five studies), baseball (one study), tennis (one study), and volleyball (one study); while the lower extremity dominant sports included football (four studies), rugby (two studies), and Australian football (one study).

The athletes' participation level ranged from recreational, amateur to semi-professional, with the majority competing within clubs or league formats. Three studies included elite or a combination of amateurs and professionals (Andersson et al., 2017, Pas et al., 2020, Wedderkopp et al., 1999). Combined female and male participant studies form the bulk of the investigation (six studies), with an almost equitable distribution between female-only (four studies) and male-only (five studies). The participants' ages ranged from 7 to 55 years old with the most significant portion of the research investigating adolescent athletes, followed by adult athletes and with a minority focus on children and youth athletes.

4.3.3 Interventions

Two of the studies investigated the same IPP (Al Attar et al., 2017, Silvers-Granelli et al., 2015), both utilising the FIFA 11+ designed to prevent football injuries. All included studies investigating the replacement or incorporation of an additional warm-up as the preventative strategy. One study (Al Attar et al., 2017) included an additional warm-down portion, and only a single study (Pas et al., 2020) included a supplementary training session. The total sample of participants investigated amounted to 19 060 athletes, and the recorded upper extremity injuries or adverse events totalled 1014 events.

The whole group applied the intervention on the field or the court. The interventions were applied for an average of 7.5 months (range of 3 to 12 months). The athletes participated in an average of 77 sessions (range of 50 to 144), consisting of an estimated 25 hours of performance. Acute shoulder and upper extremity were recorded in 14 studies, while four studies recorded overuse injuries (Andersson et al., 2017, Osteras et al., 2015, Sommervold and Osteras, 2017, Verhagen et al., 2004).

Of all the groups and participants approached, 50.52% (range 6.38% to 90.53%) declined to participate in the studies. The experimental groups experienced an average drop-out rate of 16.58% (range 2.45% - 46.34%), while the control groups experienced a drop-out rate of 18.59% (range 5.30% - 52.50). The combined average drop-out rate for both groups was 17.59%.

4.3.4 Statistical analyses

The studies analysed 83.82% of the reported sample size in the experimental groups and analysed an average of 82.73& of the control groups' sample. Two studies performed an unmodified ITT analysis (Al Attar et al., 2017, Olsen et al., 2005); one performed an unmodified ITT and per-protocol (PP) analysis; two performed a modified-ITT and PP analysis (Attwood et al., 2017, Hislop et al., 2017); four performed a modified-ITT analyses (Finch et al., 2016, Pas et al., 2020, Rossler et al., 2018, Sakata et al., 2019); four performed a PP analysis (Andersson et al., 2017, Osteras et al., 2015, Silvers-Granelli et al., 2015, Sommervold and Osteras, 2017); and two studies did not disclose the type of analysis performed but were deemed to be PP analyses. (Verhagen et al., 2004, Wedderkopp et al., 1999). Cluster adjustment was performed in six of the seven included cluster RCTs. The exception was Hislop et al. (2017).

4.4 Risk of bias within studies

The methodological quality assessment performed above (section 4.2), revealed certain specific biases in the included studies that require specific examination. Selection bias occurs when either true randomisation or allocation concealment are not performed. Half of the studies (50%) did not fully disclose their randomisation method (Attwood et al., 2017, Hislop et al., 2017, Olsen et al., 2005, Osteras et al., 2015, Sakata et al., 2019, Steffen et al., 2008, Verhagen et al., 2004, Wedderkopp et al., 1999) and four studies did not fully disclose their allocation concealment method (Osteras et al., 2015, Silvers-Granelli et al., 2015, Verhagen et al., 2004, Wedderkopp et al., 1999).

Performance bias occurs if participants and intervention delivery agents are not adequately blinded. Four studies attempted strategies to blind their participants (Al Attar et al., 2017, Attwood et al., 2017, Finch et al., 2016, Hislop et al., 2017). Agents assigned to deliver the intervention were sufficiently blinded only 14.28% of the time by two authors (Al Attar et al., 2017, Attwood et al., 2017). Three studies disclosed that they visited the experimental group more than the control group (Al Attar et al., 2017, Andersson et al., 2017, Sommervold and Osteras, 2017).

Detection bias occurs if the outcome assessors are not blinded to the participants' group allocation. Three studies did not blind assessors (Andersson et al., 2017, Hislop et al., 2017, Wedderkopp et al., 1999), while in a further four studies it was unclear if the assessors were indeed blinded (Attwood et al., 2017, Osteras et al., 2015, Sommervold and Osteras, 2017, Verhagen et al., 2004). Three studies disclosed that their control groups performed similar IPPs or extra strength training sessions (Andersson et al., 2017, Olsen et al., 2005, Osteras et al., 2015), indicating that few authors screened for supplementary sessions performed outside the confines of the sport.

Attrition bias occurs if an unequal loss of participants happens in one group, or if no reasons are provided for participants who drop-out. All the studies either suffered from a high drop-out rate or the ratio between groups was significantly skewed, except for two studies (Finch et al., 2016, Olsen et al., 2005). The occurrence of a participant leaving during a study is likely, and cluster RCTs regularly result in whole teams discontinuing and exiting the study.

None of the studies considered or excluded athletes who recently performed IPPs to prevent injuries. A significant bias that was not covered by any study is the potential effect of participation in other sports outside the research focus. An athletic population that does not include professionals has a high likelihood of participation in multiple sporting codes.

The high number of unclear assignments (29%) in the methodological quality assessments indicates that the general reporting was not transparent. This is surprising, as all but six studies claimed they followed the CONSORT guidelines (Olsen et al., 2005, Steffen et al., 2008, Sommervold and Osteras, 2017, Silvers-Granelli et al., 2015, Verhagen et al., 2004, Wedderkopp et al., 1999).

4.5 Systematic Review results

The systematic review included a primary and secondary meta-analysis with sub-group meta-analyses performed to further explore the effect of the primary analysis. The data from 13 studies was collated and synthesised to produce the primary meta-analysis (Al Attar et al., 2017, Andersson et al., 2017, Attwood et al., 2017, Hislop et al., 2017, Olsen et al., 2005, Osteras et al., 2015, Pas et al., 2020, Rossler et al., 2018, Sakata et al., 2019, Silvers-Granelli et al., 2015, Sommervold and Osteras, 2017, Verhagen et al., 2004, Wedderkopp et al., 1999). The analysis successfully provided a statistically significant effect size and thus met the primary aim to determine the effectiveness of exercise interventions to prevent shoulder injuries in sport.

In addition to the primary aim involving shoulder specific data, the data retrieved also enabled the secondary investigation into the effectiveness of exercise intervention to prevent upper extremity injuries (Al Attar et al., 2017, Andersson et al., 2017, Hislop et al., 2017, Olsen et al., 2005, Pas et al., 2020, Rossler et al., 2018, Sakata et al., 2019, Silvers-Granelli et al., 2015, Sommervold and Osteras, 2017, Steffen et al., 2008, Verhagen et al., 2004, Wedderkopp et al., 1999). A secondary meta-analysis is performed for the upper extremity.

Collation of upper extremity data from all included studies that did not provide specific shoulder injury numbers but used the traditional upper extremity and lower extremity split to record injuries was done. Studies that separately reported upper extremity from the specified shoulder injury rate were included. In instances where the study did not report the total number of injuries for the upper extremity, individual injury segments were collated into a pooled segment of upper extremity injury category.

The pre-planned sensitivity analysis was performed to test for the robustness of the results. The determination of similar effect sizes' magnitude and direction was performed and found to have little effect except for removing the high risk of bias studies. The *a priori* subgroup analysis was performed to explore the expected heterogeneity and the mechanism to resolve it. The analyses are reported from section 2.6, after addressing heterogeneity and sensitivity.

4.5.1 Heterogeneity

The studies were expected to be homogeneous enough for pooling, but the heterogeneity was expected to be high due to the significant variances between studies. The main factor is whether the heterogeneity is too substantial to provide a worthwhile meta-analysis (Melsen et al., 2014). The heterogeneity was assessed using the Tau squared (T^2) and I^2. The T^2 was zero across all meta-analyses indicating that the inconsistency found in the effect variance has a negligible effect on the results in absolute terms. This further supports the view that the random effect model and the Mantel-Haenszel statistical method in the analyses were correct as indicated by the sensitivity analyses.

The I^2 statistic is the only heterogeneity measure that required additional examination. The higher the heterogeneity *P*-value, the less significant the clinical heterogeneity (Fletcher, 2007). The primary meta-analysis produced moderate heterogeneity, which is acceptable in light of the wide variety of clinical and methodological diversity inherent in the included studies, but the heterogeneity was statistically significant requiring additional examination to discover the source. The secondary meta-analysis investigating the prevention of upper extremity injuries in sport displayed substantial heterogeneity, albeit in the lower range of the classification; hence it requires that the result be interpreted with caution.

The congruency of effect sizes with higher levels of heterogeneity can be tested with sub-group analyses to determine the cause and may possibly resolve the heterogeneity present. The heterogeneity may be due to clinical diversity which consists of differences in participants, interventions, study durations, outcomes or sample sizes (Fletcher, 2007). The pre-planned sub-groups analyses of acute ($T^2 = 0$, $I^2 = 57\%$, $P = 0.009$) *versus* overuse shoulder injuries ($T^2 = 0$, $I^2 = 36\%$, $P = 0.197$), shoulder specific programmes ($T^2 = 0$, $I^2 = 53\%$, $P = 0.046$) *versus* non-specific programmes ($T^2 = 0$, $I^2 = 26\%$, $P = 0.234$), and upper ($T^2 = 0$, $I^2 = 40\%$, $P = 0.117$) *versus* lower extremity dominant sports ($T^2 = 0$, $I^2 = 64\%$, $P = 0.016$) explored the clinical heterogeneity.

The findings reveal that investigating overuse shoulder injuries resolves moderate heterogeneity; this is because all included overuse studies were explicitly designed to assess overuse shoulder injuries and are thus more homogeneous. Non-specific intervention programmes significantly reduced heterogeneity as these studies incidentally affected the shoulder and were designed to clinically address overall injuries, with the majority of studies following the same intervention pattern. The upper extremity sports resolved heterogeneity slightly as was expected as the sports are more akin to one another. The clinical heterogeneity was expected and was reduced but not entirely resolved by sub-group analysis. This indicates that overall IPPs are more similar to one another than shoulder specific programmes and, as logically expected are more homogeneous.

The heterogeneity can be due to methodological diversity that includes differences in study designs, methodologies and inherent validity (risk of bias) of the included studies (Fletcher, 2007). The pre-planned sub-group analyses of cluster RCTs (T^2 = 0, I^2 = 38%, *P* = 0.138) *versus* RCTs (T^2 = 0, I^2 = 27%, *P* = 0.231) were used to explore the methodological heterogeneity. The results reveal that the largest combined reduction in heterogeneity comes from the differences in methodological factors. However, the heterogeneity was not resolved, and the pre-planned decision to perform the last sensitivity analysis to test the influence of the methodological quality of the included studies on the effect size is described in the section below.

4.5.2 Sensitivity analyses

Sensitivity analyses were performed with different statistical methods and effect measures that displayed a similar magnitude of effects and direction. All meta-analyses showed the same direction of effect and the majority a similar magnitude. The only sensitivity analysis that significantly influenced the effect size was achieved by removing studies with low methodological quality. The removal of studies with poor internal validity showed a significant influence on the findings. The sensitivity analysis is crucial to determine the credibility of the results.

The decision to include all studies irrespective of methodological quality was pre-planned to reduce the chance of selective inclusion bias. A meta-analysis was performed by including only methodological high-quality studies that were rated 65% or above (T^2 = 0, I^2 = 0%, P = 0.875). The results resolved the heterogeneity completely, indicating that the variances found are mainly due to the inherent risk of biases found in low-quality studies. The I^2 = 0% value may be negative but is displayed only as zero (Melsen et al., 2014).

4.6 Primary meta-analysis

Thirteen studies were pooled to investigate the effectiveness of exercise interventions to prevent both acute and overuse shoulder injuries in sport. The number of injury events and participants for both groups is reported in Figure 4.3**,** together with the results. The heterogeneity is moderate (T^2 = 0, I^2 = 53%, *P* = 0.013) in the meta-analysis. The result is statistically significant and in favour of the experimental group [0.77 (0.65 – 0.91) RR, 95% CI, *P* = 0.013].

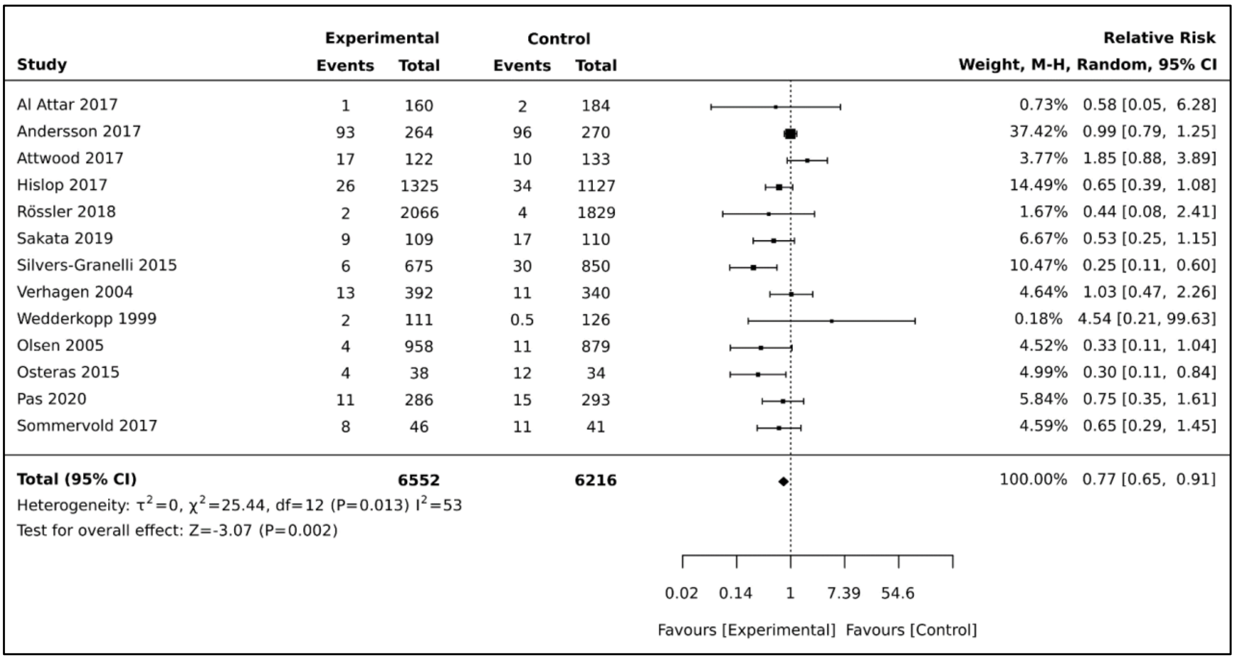


Figure 4.3: Forrest plot - Meta-analysis depicting the effect size for the prevention of total shoulder injuries

4.7 Secondary meta-analysis

Thirteen studies were pooled to investigate the effectiveness of exercise interventions to prevent total upper extremity injuries in sport. The number of injury events and participants for both groups is reported in Figure 4.4**,** together with the results. The heterogeneity is substantial (T^2 = 0, I^2 = 66%, *P* = 0.001) in the meta-analysis. The result is statistically significant and in favour of the experimental group [0.65 (0.56 - 0.77) RR, 95% CI, *P* = 0].

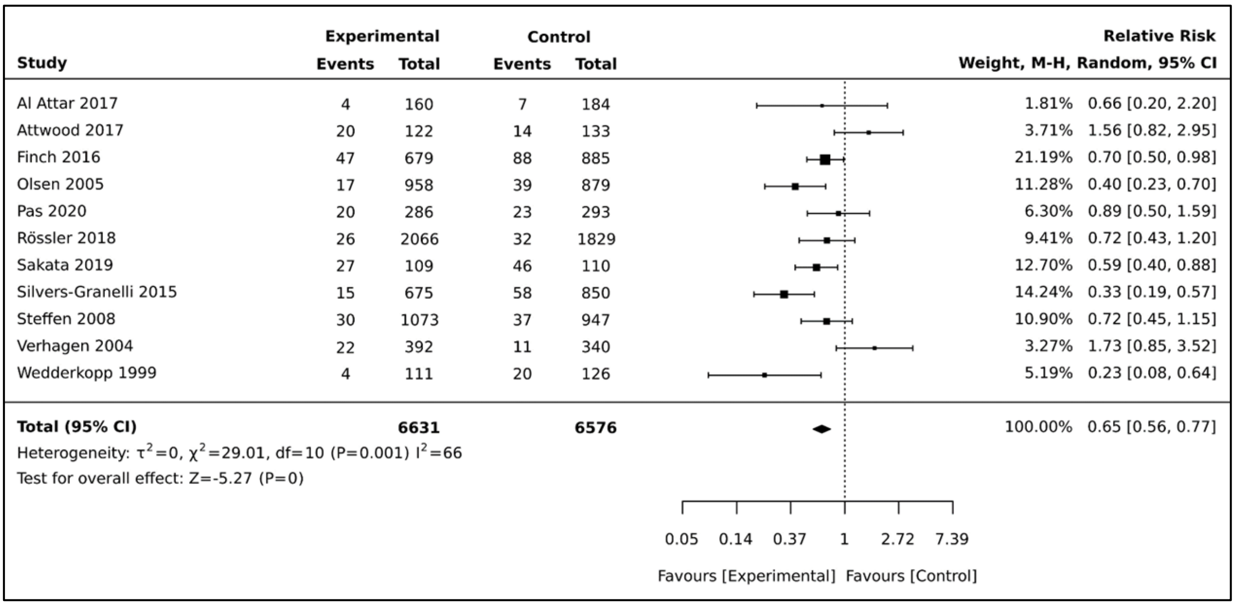


Figure 4.4: Forrest plot - Meta-analysis depicting the effect size for the prevention of total upper extremity injuries

4.8 Meta-analysis of sub-groups

4.8.1 Acute versus overuse shoulder injuries

Eleven studies were pooled to investigate the effectiveness of exercise interventions to prevent acute shoulder injuries in sport. The number of injury events and participants for both groups is reported in Figure 4.5**,** together with the results. The heterogeneity is moderate (T^2 = 0, I^2 = 57%, *P* = 0.009) in this subgroup meta-analysis, and slightly higher than the main meta-analysis. The result is statistically significant and in favour of the experimental group [0.75 (0.58 – 0.96) RR, 95% CI, *P* = 0.024].

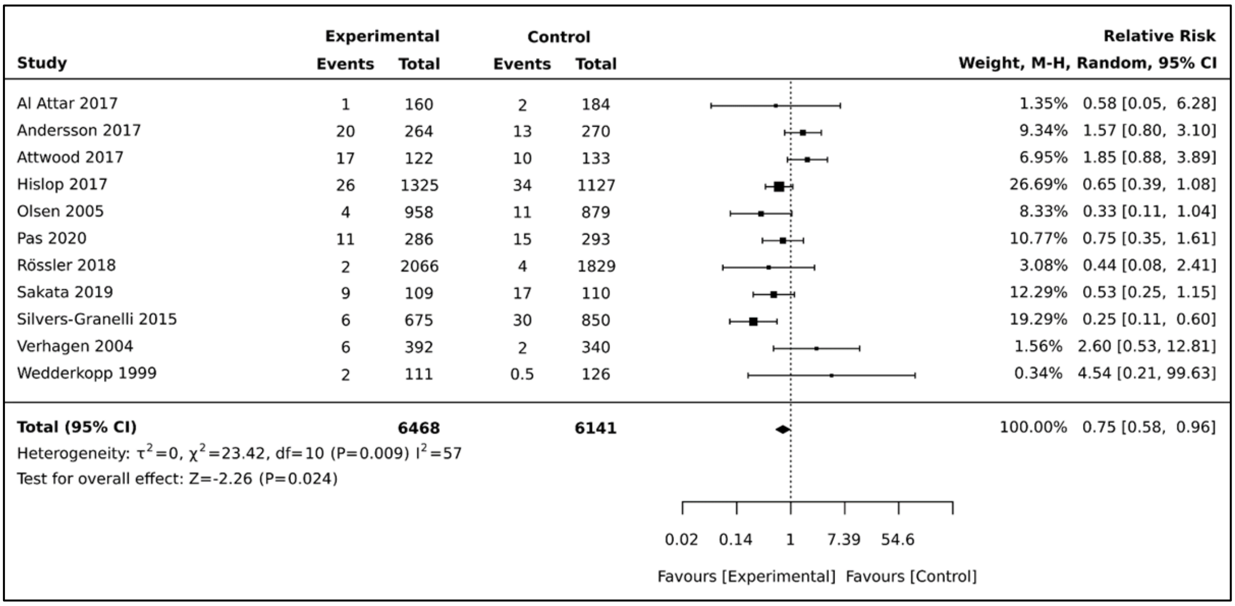


Figure 4.5: Forrest plot - Meta-analysis depicting the effect size for the prevention of acute shoulder injuries

Four studies were pooled to investigate the effectiveness of exercise interventions to prevent overuse shoulder injuries in sport. The number of injury events and participants for both groups is reported in Figure 4.6**,** together with the results. The heterogeneity is unimportant/moderate (T^2 = 0, I^2 = 36%, *P* = 0.197) in this subgroup meta-analysis and significantly less than the main meta-analysis. The result is statistically significant and in favour of the experimental group [0.79 (0.62 - 1.00) RR, 95% CI, *P* = 0.05].

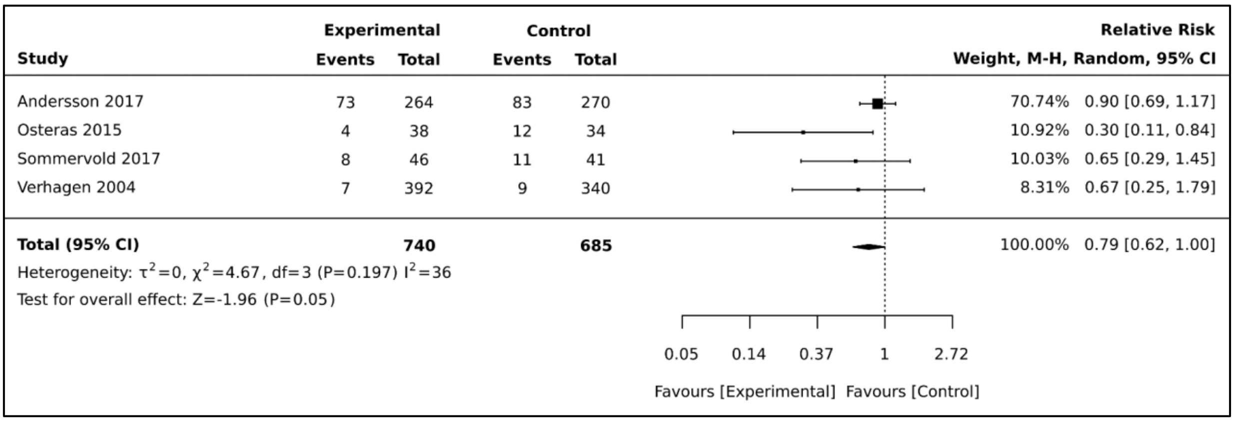


Figure 4.6: Forrest plot - Meta-analysis depicting the effect size for the prevention of overuse shoulder injuries

The results above are statistically significant and reveal that the secondary aim of providing estimates for acute *versus* overuse programmes can be produced as both meta-analyses. IPPs have a slightly greater preventative effect against acute shoulder injuries [0.75 (0.58 – 0.96) RR, 95% CI, *P* = 0.024] than overuse shoulder injuries [0.79 (0.62 - 1.00) RR, 95% CI, *P* = 0.05].

4.8.2 Shoulder specific versus non-specific programmes

Seven studies were pooled to investigate the effectiveness of shoulder-specific exercise interventions to prevent shoulder injuries in sport. The number of injury events and participants for both groups is reported in Figure 4.7**,** together with the results. The heterogeneity is moderate (T^2 = 0, I^2 = 53%, *P* = 0.046) in this subgroup meta-analysis and the same as the main meta-analysis. The result is not statistically significant but in favour of the experimental group [0.85 (0.72 - 1.01) RR, 95% CI, *P* = 0.067].

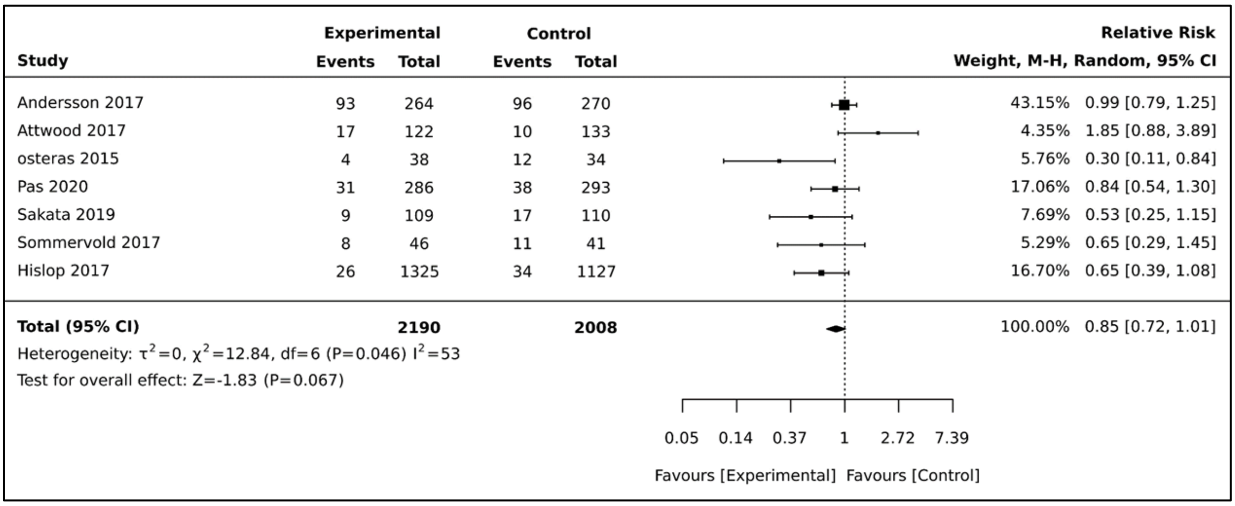


Figure 4.7: Forrest plot - Meta-analysis depicting the effect size for shoulder specific programmes

Seven studies were pooled to investigate the effectiveness of non-specific exercise interventions to prevent shoulder injuries in sport. The number of injury events and participants for both groups is reported in Figure 4.8**,** together with the results. The heterogeneity is unimportant/low (T^2 = 0, I^2 = 26%, P = 0.234) in this subgroup meta-analysis and significantly less than the main meta-analysis. The result is statistically significant and in favour of the experimental group [0.50 (0.34 - 0.74) RR, 95% CI, P = 0.001].

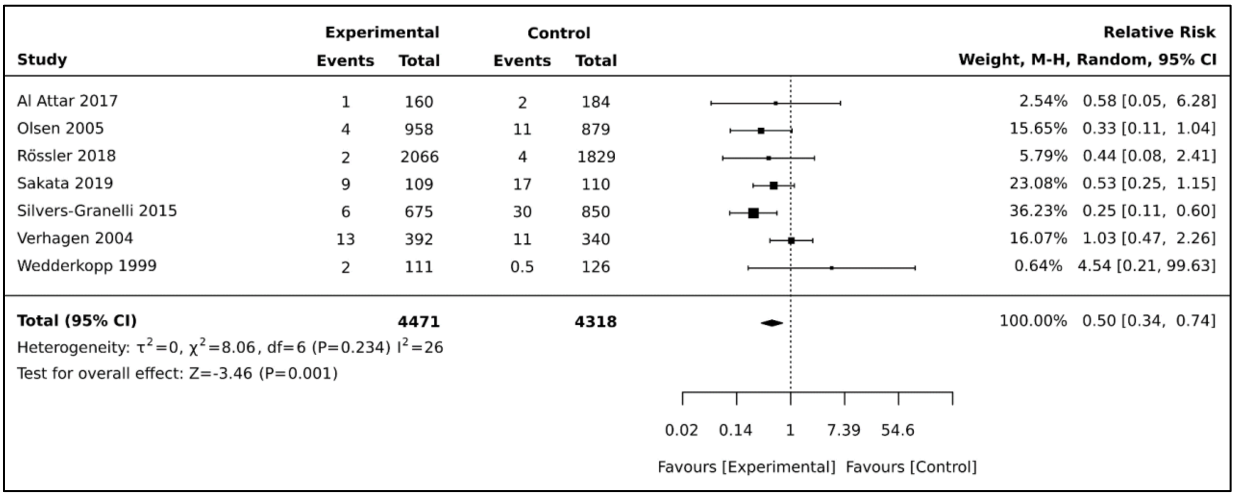


Figure 4.8: Forrest plot - Meta-analysis depicting the effect size for non-specific shoulder programmes

4.8.3 Upper versus lower extremity sports

Eight studies were pooled to investigate the effectiveness of exercise interventions to prevent shoulder injuries in upper extremity dominant sports. The number of injury events and participants for both groups is reported in Figure 4.9**,** together with the results. The heterogeneity is moderate but statistically insignificant (T^2 = 0, I^2 = 40%, *P* = 0.117) in this subgroup meta-analysis and less than the main meta-analysis. The result is statistically significant and in favour of the experimental group [0.82 (0.68 - 1.00) RR, 95% CI, *P* = 0.044].

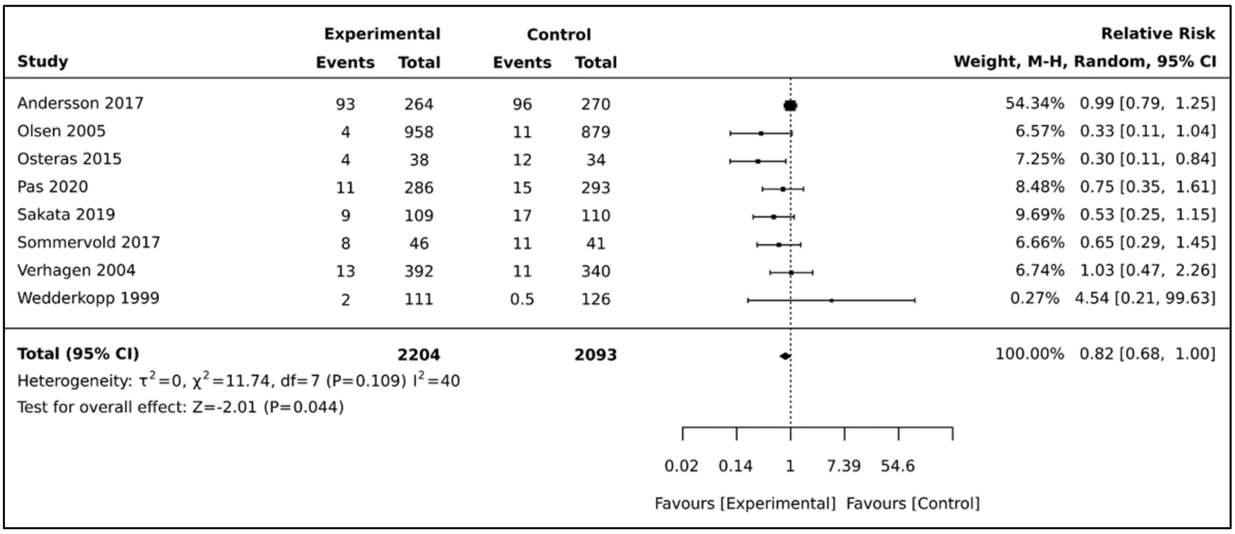


Figure 4.9: Forrest plot - Meta-analysis depicting the effect size for upper extremity dominant sports

Six studies were pooled to investigate the effectiveness of exercise interventions to prevent shoulder injuries in lower extremity dominant sports. The number of injury events and participants for both groups is reported in Figure 4.10**,** together with the results. The heterogeneity is substantial (T^2 = 0, I^2 = 64%, *P* = 0.016) in this subgroup meta-analysis and significantly more than the main meta-analysis. The result is statistically significant and in favour of the experimental group [0.61 (0.44 - 0.85) RR, 95% CI, *P* = 0.003].

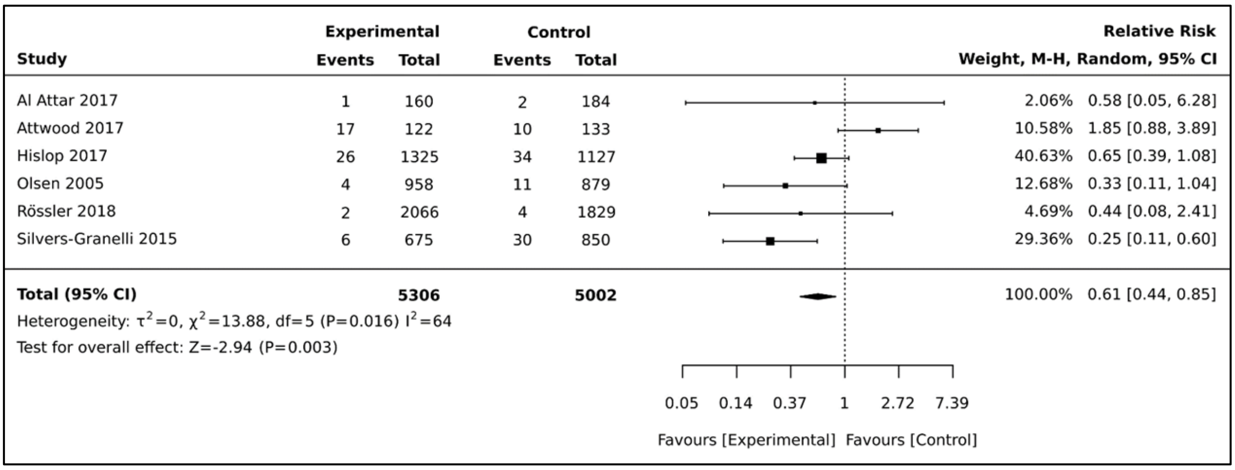


Figure 4.10: Forrest plot - Meta-analysis depicting the effect size for lower extremity dominant sports

4.8.4 Cluster RCTs versus RCTs

Seven cluster RCT studies were pooled to investigate the effectiveness of exercise interventions to prevent shoulder injuries in sports. The number of injury events and participants for both groups is reported in Figure 4.11**,** together with the results. The heterogeneity is unimportant/moderate (T^2 = 0, I^2 = 38%, *P* = 0.138) and significantly less than the main meta-analysis. The result is not statistically significant but in favour of the experimental group [0.91 (0.75 - 1.10) RR, 95% CI, *P* = 0.311].

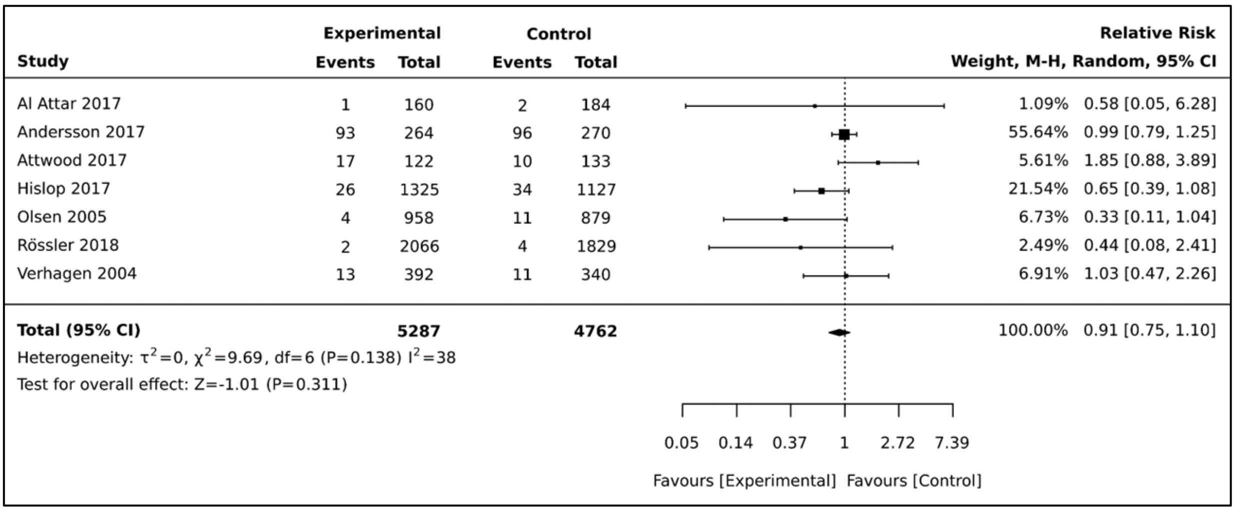


Figure 4.11: Forrest plot - Meta-analysis depicting the effect size for shoulder specific cluster RCTs

Six RCT studies were pooled to investigate the effectiveness of exercise interventions to prevent shoulder injuries in sports. The number of injury events and participants for both groups is reported in Figure 4.12**,** together with the results. The heterogeneity is low (T^2 = 0, I^2 = 27%, *P* = 0.231) in this subgroup meta-analysis and substantially less than the main meta-analysis. The result is statistically significant and in favour of the experimental group [0.49 (0.34 - 0.70) RR, 95% CI, *P* = 0].

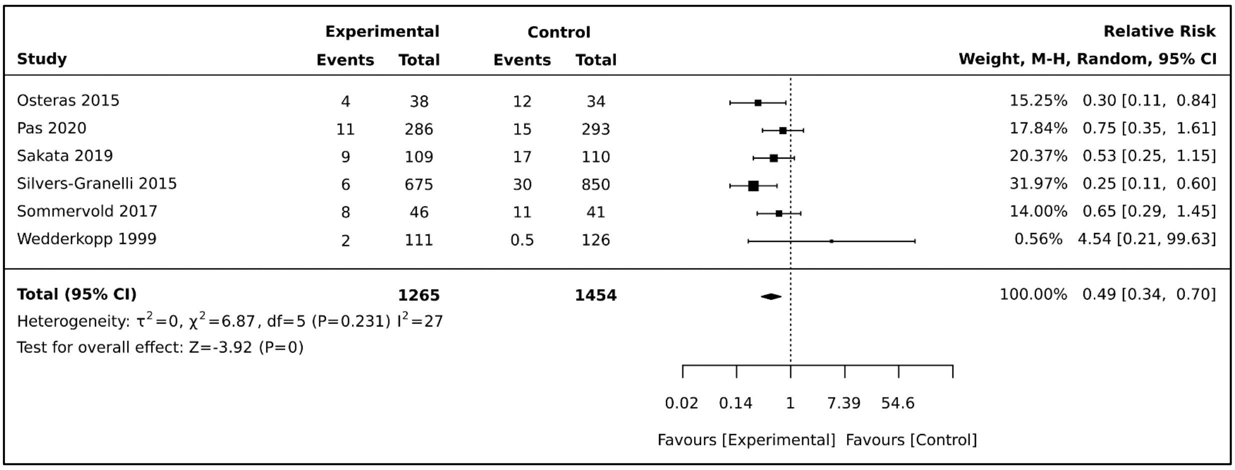


Figure 4.12: Forrest plot - Meta-analysis depicting the effect size for shoulder specific RCTs

4.8.5 Sensitivity analyses

Five high-quality studies were pooled to investigate the effectiveness of exercise interventions to prevent shoulder injuries in sports. The number of injury events and participants for both groups is reported in Figure 4.13**,** together with the results. The heterogeneity is non-existent (T^2 = 0, I^2 = 0%, *P* = 0.875) in this sensitivity meta-analysis and resolved all variance found in the main meta-analysis. The result is statistically significant and in favour of the experimental group and likely to be the most accurate reflection of the true effect [0.56 (0.38 - 0.82) RR, 95% CI, *P* = 0.002].

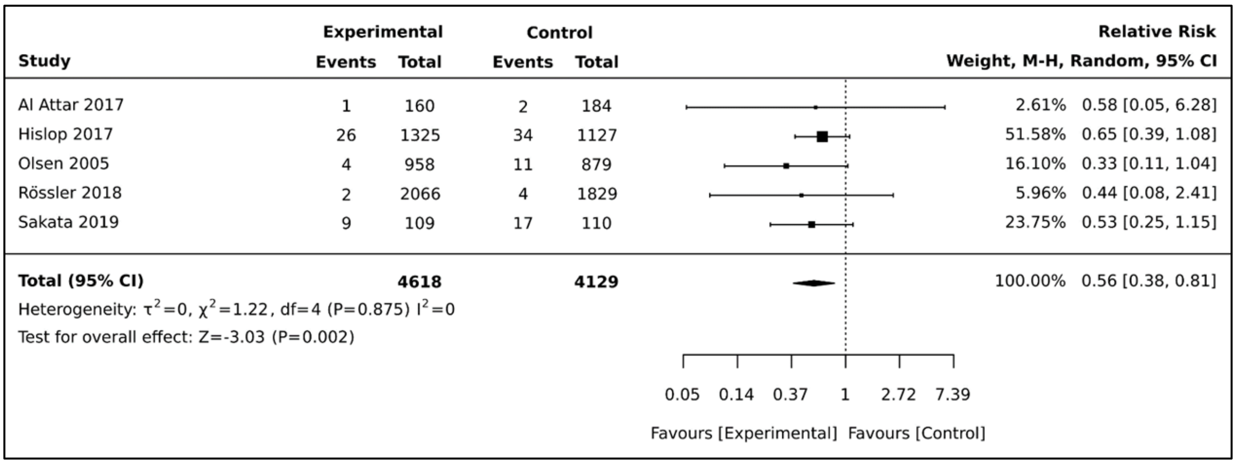


Figure 4.13: Forest plot - Meta-analysis of the high methodological quality sensitivity analysis for shoulder specific studies

4.9 Narrative Review

The secondary aim to designate and classify the varieties of exercise interventions affecting the upper extremity included in the IPPs into strength, flexibility, mobility, plyometrics, proprioception, functional or multimodal exercises that was performed and collated. The final secondary aim to describe and categorise the components of the IPP's shoulder specific exercises into a closed or open kinematic chain and establish an overview of current prevention programmes performed in research for the sporting shoulder is provided in Table 4.2.

Table 4.2: Components and volumes of exercise components

Study	Strength	Flexibility	Mobility	Proprioception	Plyometrics	Functional	Multimodal	Open kinetic chain (OKC)	Closed kinetic chain (CKC)	Upper extremity exercises totals
Al Attar 2017	0	0	0	4 (450 sec)	1 (120 sec)	3 (300 sec)	1 (120 sec)	2 (240 sec)	7 (750 sec)	9 of 27
Andersson 2017	1 (48 reps)	1 (90 sec)	1 (48 reps)	0	1 (60 reps)	0	1 (48 reps)	4 (156 reps + 90 sec)	1 (48 reps)	5 of 6
Attwood 2017	4 (30 reps + 60 sec)	0	0	0	0	0	0	2 (60 sec)	2 (30 reps)	4 of 16
Finch 2016	0	0	0	0	2 (89 sec)*	0	0	2 (89 sec)*	0	2 of 27
Hislop 2017	0	0	0	1 (30 sec)	1 (6 reps)	2 (70 sec)	0	0	4 (6 reps + 100 sec)	4 of 12
Olsen 2005	1 (180 sec)	0	0	0	0	0	3 (540 sec)	4 (720 sec)	0	4 of 17
Osteras 2015	3 (156 reps)	0	0	0	0	0	0	2 (120 reps)	1 (36 reps)	3 of 3
Pas 2020 (Sample of S1 +S3 at week 10)	1 (10 reps)	0	3 (23 reps+ 120 sec)	0	0	1 (180sec)	3 (20 reps + 80 sec)	7 (33 reps + 380 sec)	1 (20 reps)	8 of 13
Rössler 2018	2 (70 sec)	0	0	0	0	2 (21 reps)	1 (40 sec)	3 (21 reps + 40 sec)	2 (70 sec)	5 of 7
Sakata 2019	0	3	3	0	0	1	0	2	5	7 of 9

		(30 sec)	(30 reps)			(10 sec)		(20 reps +10 sec)	(10 reps + 30 sec)	
Silvers-Granelli 2015	0	0	0	0	0	2 (240 sec)	0	2 (240 sec)	0	2 of 15
Sommervold 2017	1 (36 reps)	0	0	0	1 (36 reps)	0	0	0	2 (72 reps)	2 of 2
Steffen 2008	0	0	0	0	0	2 (120 sec)	3 (270 sec)	3 (270 sec)	2 (120 sec)	5 of 10
Verhagen 2004	0	0	0	0	0	0	1 (300 sec)	1 (300 sec)	0	1 of 4
Wedderkopp 1999	0	0	0	0	0	5 (300 sec)**	0	3 (180 sec)**	2 (120 sec)**	5 of 10
TOTAL of components	**13**	**4**	**7**	**5**	**6**	**18**	**13**	**39**	**29**	**66 of 178**
TOTAL volume	280 reps + 310 sec	0 reps + 120 sec	101 reps + 120 sec	0 reps + 480 sec	102 reps + 209 sec	21 reps + 1220 sec	68 reps + 1350sec	350 reps + 2619 sec	222 reps + 1190 sec	280 reps + 310 sec

Sec – Seconds; Reps – Repetitions
** 27 exercises took approximately 20 minutes.*
*** No disclosure of program but described mainly planking and throwing which is classified as functional and half of the program consisted of incidental upper extremity exercises (5 minutes)*

4.9.1 Designation and classification of exercise intervention components

The number and type of exercise components that the included studies consisted of is summarised in Figure 4.14 below.

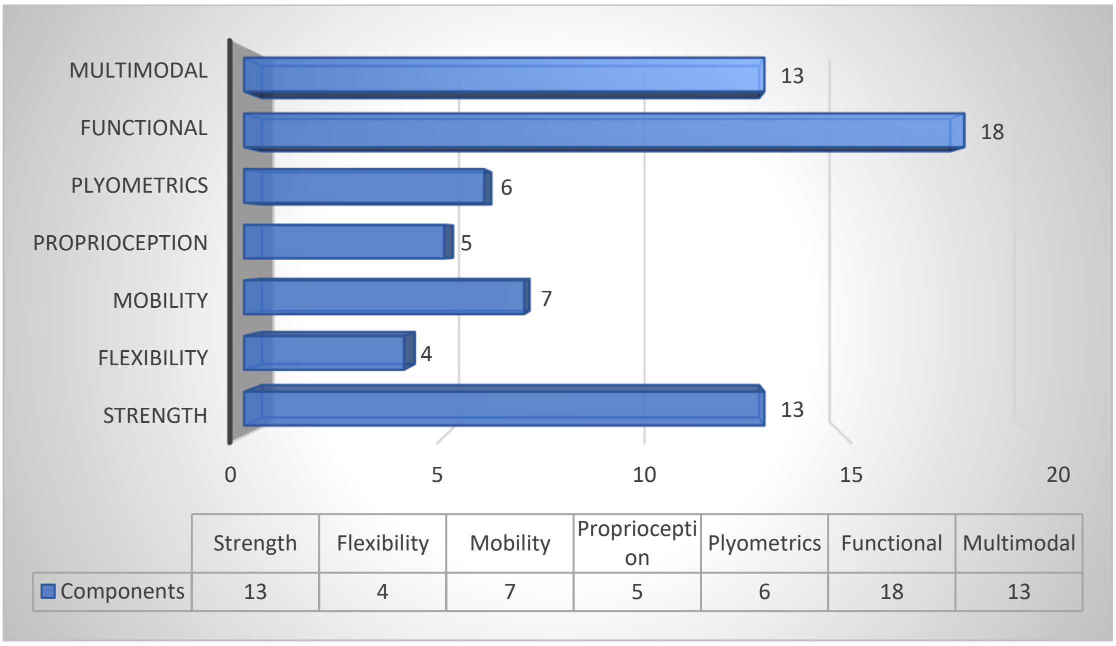


Figure 4.14: Graphic illustration of the number of exercise components in IPPs

The percentage share that each component contributes to the full IPPs of included studies is summarised in Figure 4.15 below.

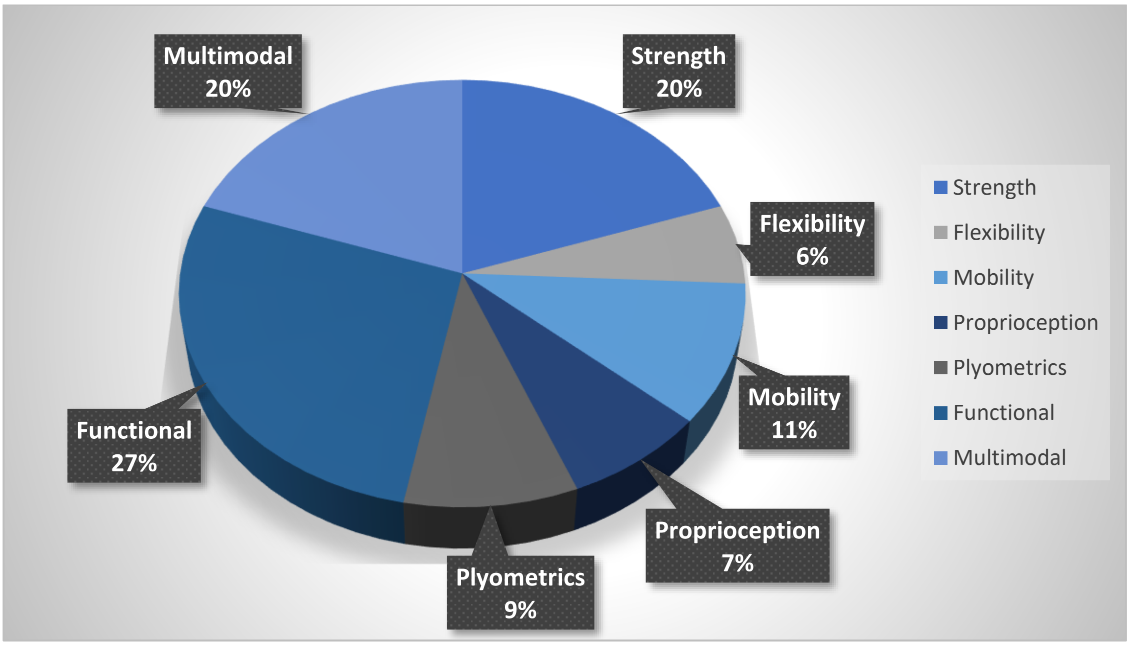


Figure 4.15: Graphic illustration of the constituents of IPPs

4.9.2 Categorisation OKC versus CKC exercises

The number of OKC *versus* CKC shoulder exercises that the included studies' IPPs consisted of are summarised in Figure 4.16 below.

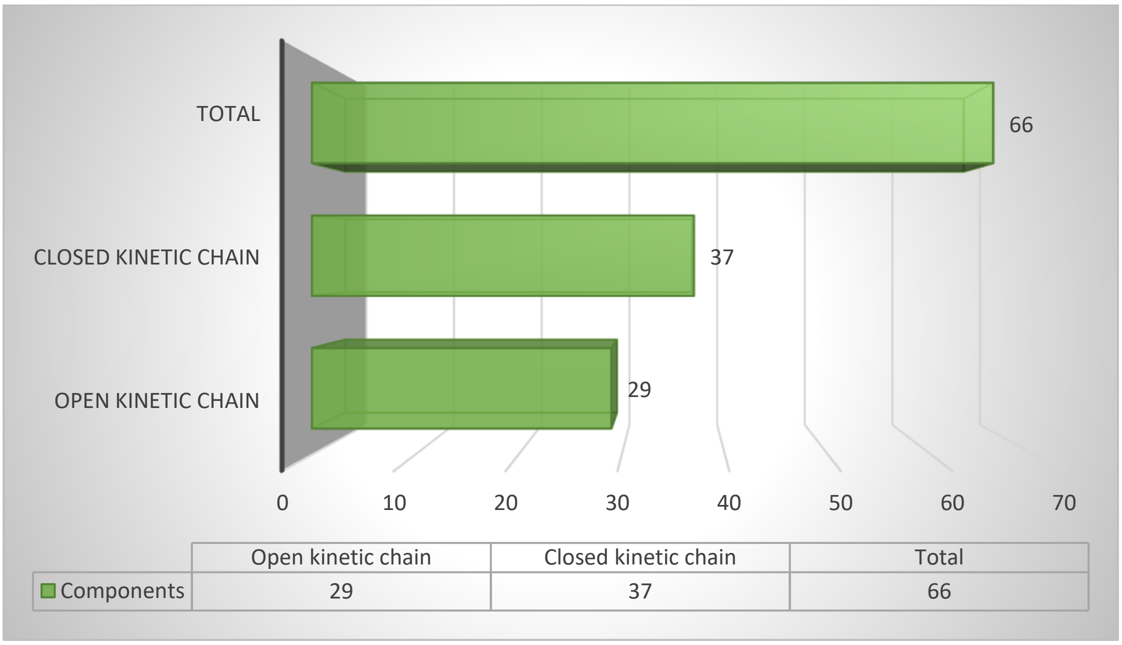


Figure 4.16: Graphic illustration of the number of OKC *versus* CKC shoulder exercises included in IPPs

The percentage contribution that OKC and CKC shoulder exercises contribute to the IPPs of included studies is summarised in Figure 4.17 below.

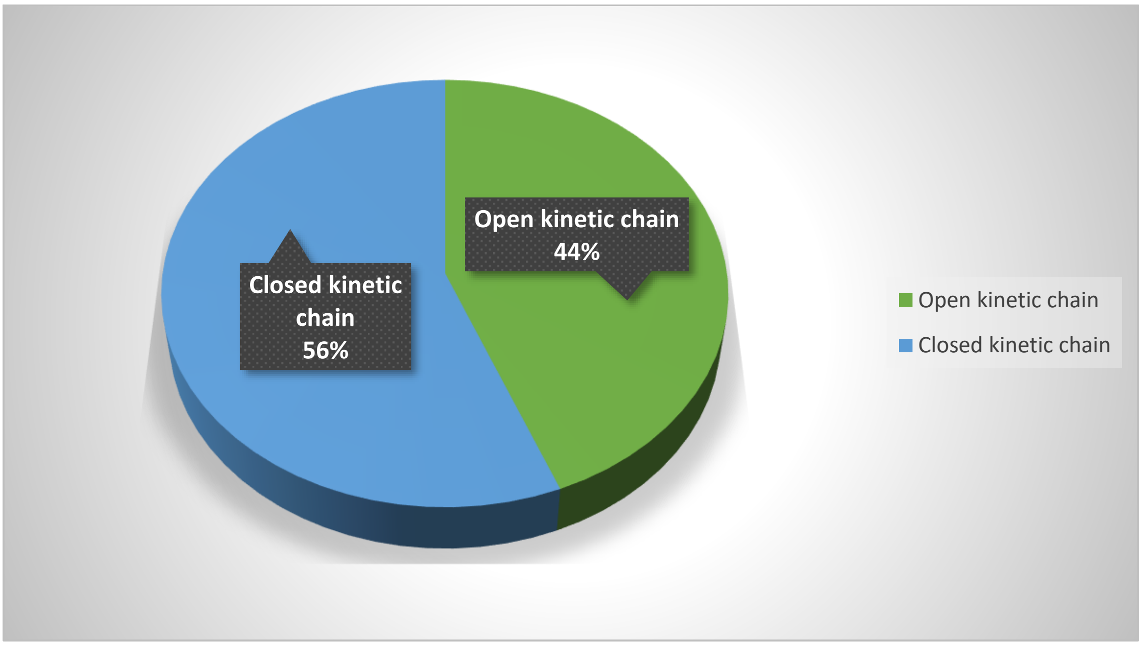
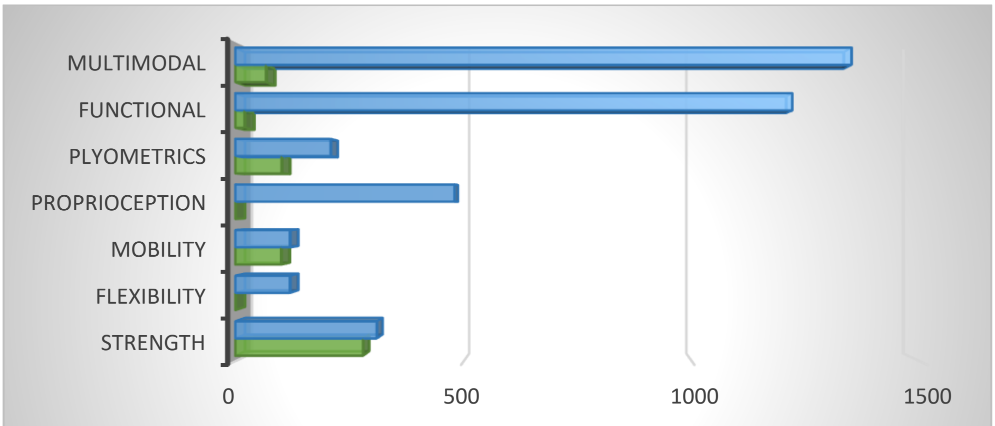


Figure 4.17: Graphic illustration of the percentage of CKC *versus* OKC shoulder exercises included in IPPs

4.9.3 Component volume overview

The total volume of all types of exercise components in the included studies' IPPs was collated. The time in seconds (sec) and the amount in repetitions (reps) are summarised in Figure 4.18 below.



	Strength	Flexibility	Mobility	Proprioception	Plyometrics	Functional	Multimodal
Time (sec)	310	120	120	480	209	1220	1350
Repetitions	280	0	101	0	102	21	68

Figure 4.18: Graphic illustration of the combined volume of exercise included in IPPs

The repetition volume of all types of exercise components in the included studies' IPPs was collated. The amount in repetitions is summarised in Figure 4.19 below.

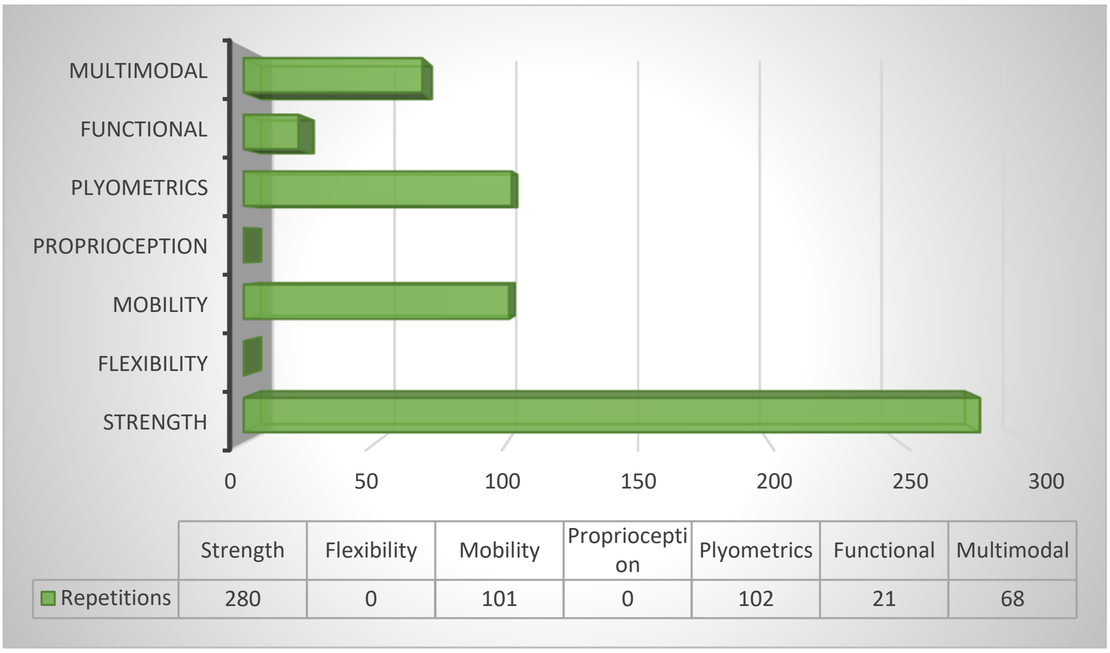


Figure 4.19: Graphic illustration of the repetition volume of exercise included in IPPs

The time-based volume of all types of exercise components in the included studies' IPPs was collated. The time in seconds (sec) is summarised in Figure 4.20 below.

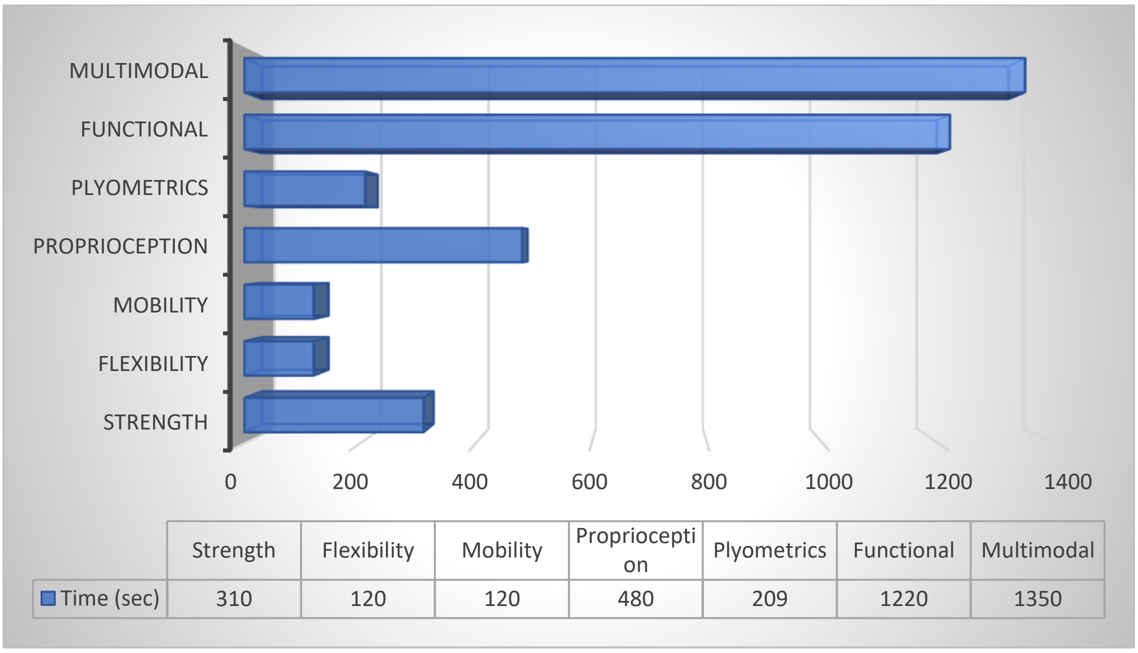


Figure 4.20: Graphic illustration of the repetition volume of exercise included in IPPs

4.10 Risk of bias across studies

The Egger test revealed no small study effect as it is statistically insignificant (*P* = 0.6390), and the findings were similar for the Harbord test (*P* = 0.9243) and Begg's test (*P* = 0.5022). The formalised testing implied that a small study effect is not present in the results, indicating a similar magnitude when comparing smaller studies with the larger studies. From the test the non-presence of publication bias can be inferred; but the study nevertheless states that a pre-planned funnel plot would be performed.

The formalised testing for publication bias included a funnel plot indicating a suitable symmetrical distribution that excludes publication bias, as seen in Figure 4.21. The plot indicates that heterogeneity was present but that it is not significant. The combination of the statistical tests and funnel plot interpretation is conclusive, and no further investigation into the extent of the publication bias is warranted.

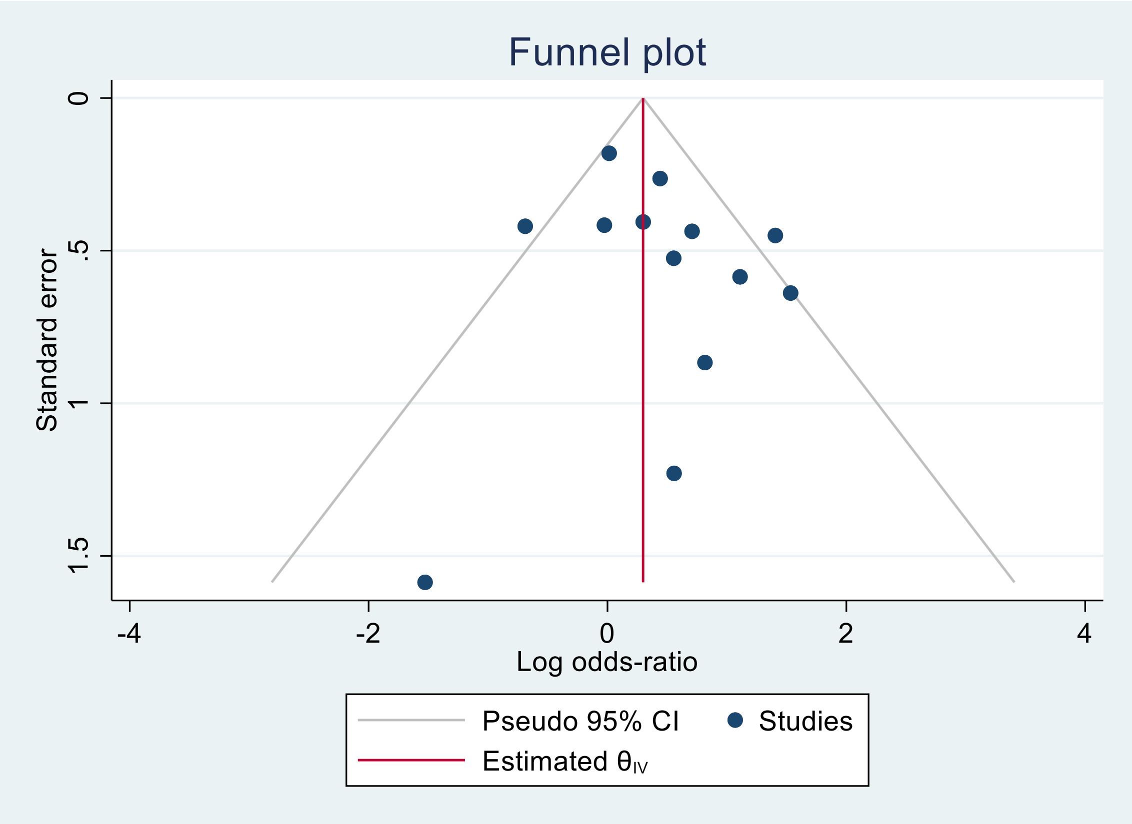


Figure 4.21: Funnel plot - Formal testing for publication bias

The trim and fill method was utilised in STATA 16 (StataCorp, College Station, USA) to determine the number of missing studies. The test indicated that three studies should be imputed on the graph's left side, as shown in Figure 4.22. The effect is inconsequential, and the results indicate that the missing studies would not alter the outcomes significantly. Thus, all formalised testing indicated a low risk of bias across the included studies.

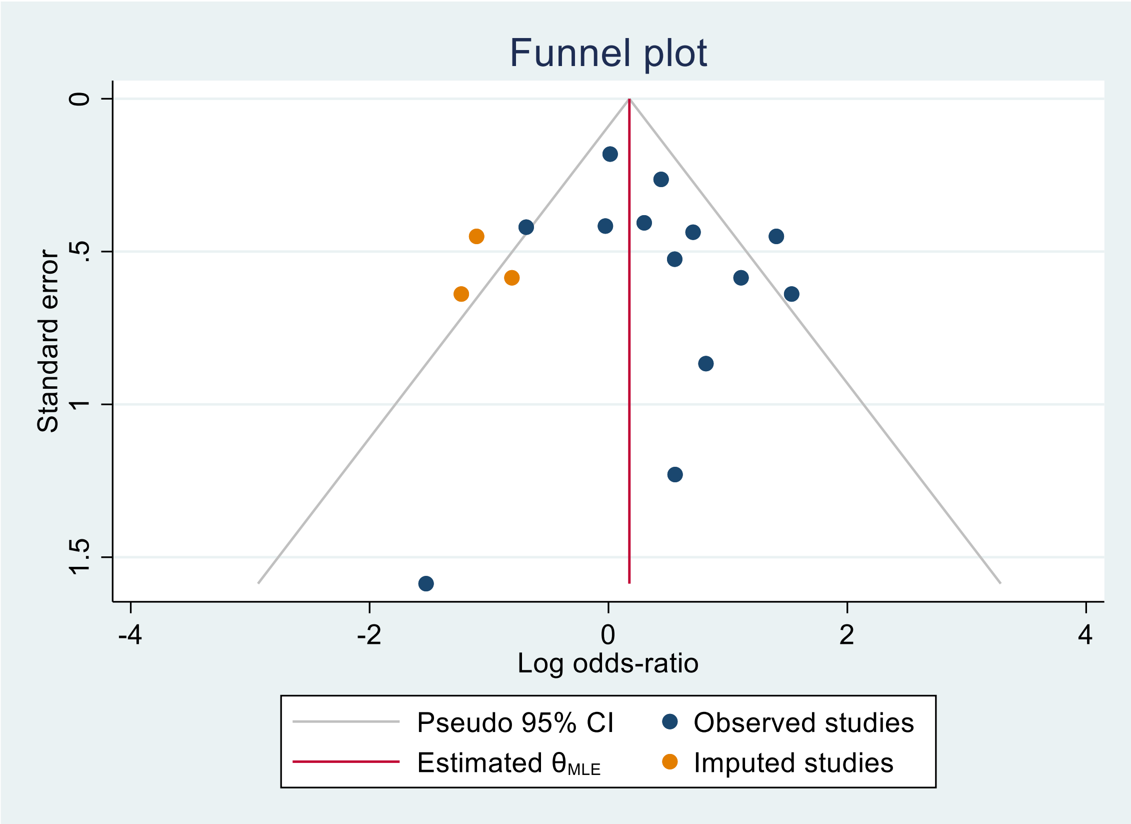


Figure 4.22: Funnel plot - Trim and fill method

4.11 Summary of results

The meta-analyses' results are summarised and presented in conjunction with the heterogeneity (T^2, I^2, and classification), average effect result (percentage), and effect *P*-value, indicating statistical significance in Table 4.3 below.

Table 4.3: Summary of the results

Group	T^2	I^2 (%)	Heterogeneity	Result (RR, 95% CI)	Average result (%)	Effect P-value
Shoulder injuries	0	53	Moderate (*P* = 0.013†)	0.77 (0.65 - 0.91)	23	*P* = 0.002*
Upper extremity injuries	0	66	Substantial (*P* = 0.001†)	0.65 (0.56 - 0.77)	35	*P* = 0*
Acute Shoulder injuries	0	57	Moderate (*P* = 0.009†)	0.75 (0.58 - 0.96)	25	*P* = 0.024*
Overuse shoulder injuries	0	36	Unimportant/ Moderate (*P* = 0.0197)	0.79 (0.62 - 1.00)	21	*P* = 0.05*

Shoulder specific programmes	0	53	Moderate (*P* = 0.046†)	0.85 (0.72 - 1.01)	15	*P* = 0.067
Shoulder non-specific programmes	0	26	Unimportant/Low (*P* = 0.234)	0.50 (0.62 - 1.00)	50	*P* = 0.001*
Upper extremity sports	0	40	Unimportant/ Moderate (*P* = 0.117)	0.82 (0.68 - 1.00)	18	*P* = 0.044*
Lower extremity sports	0	64	Substantial (*P* = 0.016†)	0.61 (0.44 - 0.85)	39	*P* = 0.003*
Cluster RCTs only	0	38	Unimportant/ Moderate (*P* = 0.138)	0.91 (0.75 - 1.10)	9	*P* = 0.311
RCTs only	0	27	Unimportant/ Low (*P* = 0.231)	0.49 (0.34 - 0.70)	51	*P* = 0*
Removal of high risk of bias studies	0	0	None (*P* = 0.875)	0.56 (0.38 - 0.82)	44	*P* = 0.002*

RR – Relative risk; CI - Confidence interval; RCT - Randomised controlled trial
Heterogeneity scale: Unimportant (0 - 40%), moderate (30 - 60%), substantial (50 - 90%), and considerable (75 - 100%)
† - Statistically significant heterogeneity (significance set as P ≤ 0.1)
** - Statistically significant effect (significance set as P ≤ 0.05)*

4.12 Conclusion of results

All aims as set out have been achieved as results have successfully been produced to answer all the research questions. Exercise interventions are effective to prevent shoulder injuries in sport with an effect of 0.77 RR [(0.65 - 0.91), 95% CI, *P* = 0.002] and with heterogeneity resolved with an effect of 0.56 RR [(0.38 - 0.82), 95% CI, *P* = 0.002]. The secondary aim to produce acute *versus* overuse shoulder injuries estimates revealed that acute shoulder injuries [0.75 (0.58 – 0.96) RR, 95% CI, *P* = 0.024] can be prevented more effectively by exercise intervention than overuse shoulder injuries [0.79 (0.62 - 1.00) RR, 95% CI, *P* = 0.05] in sport.

The discussion in Chapter 5 will link the results found in this Chapter with the current literature. The included studies, the methodological quality, the study characteristics, the risk of biases, the effects sizes, and the exercise components will be contrasted to the literature review in Chapter 2 as well as available evidence.

CHAPTER 5 - DISCUSSION

5.1 Introduction

High-quality evidence consisting of systematic reviews and meta-analyses has consistently shown that exercise interventions can reduce lower extremity injuries by approximately 50% (Crossley et al., 2020, Finch et al., 2019, Huang et al., 2020, Lauersen et al., 2014) and overall injuries by at least 35% (Al Attar et al., 2016, Al Attar and Alshehri, 2019b, Emery and Pasanen, 2019, Faude et al., 2017, Hubscher et al., 2010, Leppanen et al., 2014, Rossler et al., 2014). The literature advocates the use of NMT exercises and IPPs as the preeminent training prevention strategy to prevent injury across all sporting codes, populations and environments.

In this systematic review, the effectiveness of exercise interventions to prevent shoulder injuries in sport was ascertained by means of meta-analysis synthesis. This review further provided acute *versus* overuse effect sizes for shoulder injuries. The components of shoulder exercise prevention programmes were classified and collated. The type of kinetic chain of each exercise was categorised and organised for presentation. The results revealed a significant effect in favour of applying these exercise interventions in the form of IPPs.

To the author's knowledge, this is the first systematic review to specifically provide estimates of the prophylactic effect that IPPs have on shoulder injuries or upper extremity injuries in general. Furthermore, it is the first systematic review to produce a meta-analysis on the topic while providing a sub-group analysis between acute and overuse shoulder injuries. The various sub-group analyses delved further into the robustness of the outcomes for specific pre-identified factors and provided compelling evidence for the generalisation of the results.

This systematic review achieved the pre-set aims as laid out in the *a priori* protocol. This accomplishment enables the increase in awareness of shoulder IPPs, empowering coaches and athletes alike to appreciate beforehand what results can be expected by performing these programmes. The overview of the exercise components included in IPPs provides a roadmap of the typical shoulder prevention programmes applied in contemporary practice. The review can influence current best-practice guidelines as it acts as a departure point in designing or modifying specific and targeted shoulder interventions.

The results endorse the effectiveness of a primary prevention strategies in the shoulder to prevent injury and improve athletes' health and well-being. The research corresponds with South Africa's emphasis on primary prevention and can be translated seamlessly into a local context. The ease and minor equipment requirements for NMT IPPs allow for the implementation in several contexts. The investigated IPPs are accessible enough for the sporting communities in rural areas. The results are particularly applicable to South African upper extremity dominant sports such as netball, hockey, swimming, tennis, athletics (field events) and cricket.

The unique characteristics of the OKC upper extremity have been investigated. The results gained from this study, enables extrapolation and verify the effectiveness of exercises intervention to prevent injuries in the shoulder and upper extremity for the first time. The results confirm the causal relationship between exercise interventions and injury prevention in the upper extremity, particularly in the shoulder.

5.2 Discussion of general study qualities

5.2.1 Geographical and temporal influences on injury prevention

The majority of research originated from Europe, with the Scandinavian countries producing most of the upper extremity research. The dominance in producing upper extremity research and particularly shoulder related research from these geographical areas is not surprising. Several of the Scandinavian countries list handball as their national sport, and a large portion of the research is attributed to the highly respected Oslo Sports Trauma Research Centre (OSTRC) or its researchers (Andersson et al., 2017, Clarsen et al., 2015, Fredriksen et al., 2020).

The OSTRC has a strong research focus on overuse injuries and upper extremity injuries (Clarsen et al., 2020). The centre has been responsible for developing various shoulder intervention programmes and for compiling questionnaires designed to investigate overuse shoulder injuries (Andersson et al., 2017, Osteras et al., 2015, Sommervold and Osteras, 2017). The centre provides funding for these types of studies and provides a springboard for researchers to perform exercise intervention studies, which unfortunately can be costly to execute due to long monitoring periods and multi-site implementation.

Generally, countries have a propensity to investigate popular or national team sports for utilitarian reasons as it can make the most significant impact on injuries and the less lofty reason of cost-effectiveness (Rossler et al., 2019). The included study of Rossler et al. (2018) ran a cost-effectiveness analysis in conjunction with their study and found a 51% reduction in cost (Rossler et al., 2019). Demonstrating the epitome of the complex system approach as policymakers obtained the necessary information to drive for broader implementation from outside the sport's structure (Emery and Pasanen, 2019).

Apprehensions exist pertaining to the reproducibility of the results in an African context. The studies investigating the sports of rugby (Attwood et al., 2017, Hislop et al., 2017) and football (Al Attar et al., 2017, Crossley et al., 2020, Faude et al., 2017, Rossler et al., 2018, Silvers-Granelli et al., 2015) are a persuasive argument to nationwide implementation in South Africa. The South African Rugby Union (SARU) has introduced BokSmart as the national rugby safety programme. The programme has been implemented comprehensively, as coaches are required to attend annual mandatory training. The BokSmart programme demonstrates an adaptation model that has proven its efficacy in some areas but has not reached the level for large scale cluster RCTs included in this review to verify its effectiveness (Brown et al., 2015).

On the other hand, the South African Football Association (SAFA) seems to have dropped the ball. The free availability of the FIFA 11+ protocol, coupled with low equipment requirements and an existing partnership with FIFA, makes the poor implementation regrettable. The SAFA website has neither information campaigns nor links to the free programme. SAFA does not need to re-invent the wheel as the FIFA 11+ has a proven track record in an African context (Owoeye et al., 2020) and is ideally suited for a total adoption model. The poor execution, and at times, discretionary application by coaches nationally appear inexcusable if contrasted to the proven effectiveness of preventing injuries (Al Attar et al., 2016, Al Attar and Alshehri, 2019b).

The included studies cover a period of 21-years. The majority of studies is relatively recent, the exception being the study by Wedderkopp et al. (1999). This study investigated the effectiveness of balance board training in preventing lower extremity injuries, and unexpectedly the study registered upper extremity injuries. The documenting of upper extremity data was not standard procedure in this period, and it may be that the information was critical in an upper extremity dominant sport like handball. The robust search strategy was able to find incidental shoulder injury data in other more recent literature as well.

The topic of shoulder injury prevention has recently been receiving more attention and consideration. In the previous decade, attention to shoulder and overuse injuries was limited (Klugl et al., 2010, McBain et al., 2012a). The awareness of upper extremity injury has increased as injury surveillance programmes have improved the recording (an adaptation of definitions) and detection (inclusion of subsequent injuries) of these injuries, resulting in the predictable influx of studies (Cools et al., 2020). Despite an inflow of contemporary literature, a comprehensive systematic review on this subject was unachievable due to a lack of substantial literature as little as four years ago (Asker et al., 2018).

Despite South Africa's participation in a vast number of upper extremity driven sports, with established infrastructure, the country has not produced a large scale RCT investigating shoulder injury prevention. The current research focus is on step one and two of the Sequence of Prevention model and steps one to four in the TRIPP model (Burger et al., 2017, Dutton et al., 2019, Olivier et al., 2020). The country is poised for the challenge in this new decade of complex systems thinking and increased adherence to academic rigour (Emery and Pasanen, 2019) to produce high-level injury prevention research in sports with established resources and structures like rugby, netball, cricket, swimming, rowing, football and tennis.

5.2.2 Examination of demographics and characteristics

The sporting codes included ranged over seven distinct sporting codes. The variety of sporting codes featured in this systematic review was deemed adequate to generalise the finding beyond those sports, as other systematic reviews on multi-sports' injury prevention included six (Lauersen et al., 2014) and four sporting codes in the most recent review (Lauersen et al., 2018), respectively. The equal distribution of upper extremity *versus* lower extremity sport improves this systematic review's strength and generalisability. The most investigated sport is soccer in other lower extremity systematic reviews, and the only notable missing sport in this review is basketball (Mugele et al., 2018, Vriend et al., 2017).

The non-stratification of the results by age and sex was decided *a priori.* This systematic review is a pioneering review on the topic, with other reviews not finding enough literature to collate (Asker et al., 2018). Any additional exclusion criteria induced by stratification were deemed undesirable. Similar to the sporting codes, the included studies covered the whole age spectrum of participating athletes from child athlete to master (veterans) divisions. Research trends reveal a more significant effect in younger athletes but require further investigation into the mechanism facilitating this result (Faude et al., 2017, Rossler et al., 2014, Rossler et al., 2018).

The sexes were represented equally with both female-only and male-only studies included with the mixed-sex studies. Providing a broad benchmark against which more specific single-sex investigations can, in future measure their results against. The literature indicates that complete systematic reviews are devoted to under-researched participants, and in terms of sex this will mainly be female athletes (Bruder et al., 2020, Caldemeyer et al., 2020, Crossley et al., 2020). The research in such a specific sub-group tends to follow more generalised reviews as in this case.

The ratio of professional athletes *versus* amateur athletes displayed acceptable ranges, as the assumption regularly exists that most of the research is performed on professional players. Vriend et al. (2017) found that the majority of injury prevention research was performed on a non-professional sporting population. A similar finding resulted from this systematic review in that the research included a range of participation levels; however, most research was done on the recreational and amateur sporting community. The explanation is that professional teams are reluctant to apply untested systems, and if they form part of the control group, the loss of potential advantages will result in prompt discontinuation.

Mugele et al. (2018) classified elite athletes as professional athletes in their systematic review and produced their results with a 3:2 ratio of amateur athletes *versus* professionals. This systematic review had an approximately 3:1 ratio of amateur *versus* professionals, indicating that professional athletes were underrepresented in this study. The ratio may be misleading as the athletes included in the amateur classification ranged from recreational to semi-professional and the number included is substantial. The professional athlete pool is by far the smallest, with a distinctive classification and cut-off. Thus, the current findings are valid across the continuum of participation, and it is up to future studies to show if a diminishing effect will in fact occur in a sample containing only professional athletes.

The broad spectrum of sports participation levels allows for generalisation across the competitive levels. Uniformly, like the other study characteristics, the level of participation traverses the available continuum to produce material and inclusive results. Future studies are encouraged to investigate specific participation levels and further refine the magnitude of the effect on each level of participation. The evidence is conflicting regarding whether higher-level athletes benefit less from exercise interventions (Dijksma et al., 2020, Faude et al., 2017, Rossler et al., 2014).

This systematic review included 15 RCT studies, which are comparable to other reviews (Hubscher et al., 2010, Emery et al., 2015b, Petushek et al., 2019, Dijksma et al., 2020, Mugele et al., 2018). The number of included studies is conversely limited to broader reviews that did not delimit the population or intervention (Leppanen et al., 2014, Lauersen et al., 2014, McCrary et al., 2015, McBain et al., 2012b, McBain et al., 2012a). The meta-analyses were performed with 13 studies which were more than sufficient, considering a median of three primary studies is the minimum recommendation when performing a meta-analysis (Cheung and Vijayakumar, 2016).

5.2.3 Examination of the interventions employed

All included studies followed the warm-up training strategy except for the study of Pas et al. (2020), which included a supplementary non-mandatory training session. Their compliance could unfortunately not be verified, and as such it is unclear how many participants actually completed the additional sessions. The literature typically promotes the warm-up strategy as the most common approach, and it is used to increase general fitness or skills (Vriend et al., 2017, Faude et al., 2017).

The research confirmed the popular application of evidence-based warm-ups to reduce injuries, which has become the norm in practice (Leppanen et al., 2014). The development and adoption of warm-ups are rapid when considering that the review of Fradkin et al. (2006) found the results inconclusive and could neither recommend nor oppose the practice. The quality of programme design and component inclusion has allowed practically consistent positive outcomes; the question is no longer whether it works, but how well it works. The ceiling effect has not been reached, and progressive improvement may one day facilitate attaining the ultimate effect, but not in the foreseeable future.

A remarkable trend that was revealed during synthesis is the role of warm-downs. Embracing of a complex system method is reflected by the intervention approach in the Al Attar et al. (2017) study where the FIFA+ programme was utilised for both warm-up and warm-down and as such provided NMT during a fatigued state (Hanlon et al., 2020). The study was a superiority trial and proved the effect superior over the practise of only using the programme as a warm-up. Researchers should take note of this unique element in future investigations and examine the effects of the application of IPPs in a fatigued state.

The modification or alteration of training habits requires buy-in from the athletes, coaches and staff to change (Klugl et al., 2010). The replacement of warm-ups was so effective and straightforward despite studies like that of Fradkin et al. (2006), that the concept of warm-up has seeped into the population's collective consciousness. The fact that warm-ups previously could not show the ability to prevent injury was neither relevant nor considered. Today warm-ups are considered gospel and they will be reinforced further for generations to come irrespective of the packaging they are delivered in or the content featured.

A parallel can be drawn with stretching, and in fact, stretching may be responsible for the lack of effects found in the previous warm-up reviews. Stretching is part of the population’s collective consciousness, and it is touted by the general population for its protective effect against injury, despite most reviews’ consensus that stretching is at best ineffectual and, at worse harmful (Dijksma et al., 2020, Leppanen et al., 2014, McCrary et al., 2015).

Prudent researchers will continue to test the efficacy of different types of stretching until the expectation for stretching is met and the scientific community is satisfied with the evidence. Curious researchers may start their journey in amalgamating the needs and wants of the sporting community with the 20-second static stretching method (Sato et al., 2020, Takeuchi and Nakamura, 2020).

5.2.4 Examination of the statistical methods utilised

Cluster studies have less independent events than RCTs and require cluster adjustment to reduce potential confounding of the results by limiting power overstatement (Emery, 2007, Lauersen et al., 2014, Nielsen et al., 2020b). A recent systematic review by Dijksma et al. (2020) found that only one cluster RCT had applied cluster adjustment while in this review, only one had not done so explicitly. Generally, the included cluster studies performed adequate statistical analyses.

The recommendations are that effectiveness studies should always perform an ITT analysis (Liberati et al., 2009). ITT analysis in injury prevention is regarded to underestimate results due to the missing data brought about by the high attrition rate or lack of compliance. This assumption is not always correct, as Lauersen et al. (2014) found that the effect sizes showed a more significant beneficial effect when excluding studies that did not report the method of ITT analysis.

A study with deficient compliance and high attrition can produce inconclusive results with ITT analysis, despite high-quality programming or content (Pas et al., 2020). A substantial number of studies circumvent the loss of data by performing an *ad-hoc* modified-ITT or use statistical methods to infer the potential loss of data which are not ideal (Attwood et al., 2017, Finch et al., 2019, Hislop et al., 2017, Pas et al., 2020, Sakata et al., 2019). The CONSORT guidelines require ITT analysis as the standard procedure to maintain high-quality evidence (Moher et al., 2003).

The included studies did not deal with the missing data correctly and did not rigorously follow the ITT principles, thus producing a hybrid modified-ITT. The finding is similar to the field of orthopaedics, where RCTs were shown to not adhere to the prescribed model to perform an ITT analysis (Herman et al., 2009). The studies do not explicitly state that they lapse into a PP analysis; if a proper ITT analysis cannot be performed, modification occurs *on* various levels and stages until statistical analysis can be performed.

An investigative study by Gupta (2011) reported the advantages of ITT analysis: the results are unbiased estimates of the treatment effect in a practical clinical setting that aims to maintain sample size and statistical power, enabling the reduction of type I errors and increasing generalisability. The author reported the disadvantages as possible dilution and heterogeneity due to non-compliance and mixing of groups (drop-outs, pre-test completed, both pre-test and post-test completed), resulting in conservative treatment effects that can include type II errors.

The reporting standards require an ITT analysis and compel researchers to conduct a modified-ITT analysis as a review indicates only 38% perform complete and true ITT analyses (Joseph et al., 2015). This quasi-modified ITT is not a pre-planned and acceptable method but an *ad hoc* modification that is used as a guise to demonstrate adherence to the guidelines. The modified-ITT justifies excluding certain randomised individuals who are usually participants excluded after allocation and participants who did not receive the intervention (Gupta, 2011).

The issue is that trialists struggle to appropriately deal with missing data as an average of 12% of participants drop out of musculoskeletal studies which result in an unsuitably modified-ITT analysis, the findings of which are biased and invalid (Joseph et al., 2015). The definition in the included studies reported inconsistent definitions for modified-ITT analysis. Other studies have found RCTs use arbitrary and contradictory descriptions of the modified-ITT methodology, in part due to a lack of guidelines for modified-ITTs (Gupta, 2011, Joseph et al., 2015, Nielsen et al., 2020a).

The model injury prevention study should include both a pre-planned modified-ITT and PP analysis. The PP analysis can demonstrate whether an effect exists when the problems with compliance and attrition are excluded. The results can be tempered with the results of the ITT analysis findings, to indicate the actual effect. The PP analysis is often rejected as it may overestimate the effect; however its sensitivity may also detect adverse or harmful effects. Attwood et al. (2017) found that their programme may possibly be harmful to the shoulder only when performing the PP-analysis.

5.3 Principal Finding: The prevention of shoulder injuries

The primary meta-analysis revealed that almost a quarter of shoulder injuries could be prevented through IPPs. The moderate and statistically significant heterogeneity inherent in the result restricts the external validity; however, this was resolved with a sensitivity analysis in which studies of low methodological quality were removed. Once these studies were excluded, the results showed that slightly less than half of shoulder injuries could be prevented. Since no heterogeneity was found in the analysis, the results can be generalised with a high level of certainty.

The sensitivity analysis seems to indicate that the heterogeneity did not subsist in real inconsistency but as an artefactual element generated by internal validity problems. This review provided the additional evidence necessary to endorse previous findings that exercise intervention can prevent shoulder injuries that was inferred from the lower extremity and general injury studies.

Very few modern intervention programmes do not produce a reduction in the risk of sports injury (Mugele et al., 2018). The meta-analysis in this systematic review included 13 RCTs and cluster RCTs, of which the data weas pooled in order to produce the findings. Only three included studies (Pas et al., 2020, Sommervold and Osteras, 2017, Steffen et al., 2008) did not find a prophylactic effect which is similar to the review by Emery et al. (2015b).

The magnitude of the effect size is similar to those calculated in systematic reviews in the lower extremity, albeit with a marginal lower and upper range of effect (Crossley et al., 2020, Finch et al., 2019, Huang et al., 2020, Lauersen et al., 2014). The likely reasons for the superiority of lower extremity programmes are that the topic has been the beneficiary of a disproportional amount of research that has been accumulating throughout an extended period (Leppanen et al., 2014, McBain et al., 2012a, McBain et al., 2012b, Vriend et al., 2017), providing opportunities for refining, which the upper extremity and in particular the shoulder lacks (Asker et al., 2018, Cools et al., 2020).

The benefit of modification and refining IPPs based on a robust research foundation is perfectly illustrated in the sport, which has been the receiving end of the most investigations, namely football (Crossley et al., 2020, Owoeye et al., 2020, Vriend et al., 2017). Al Attar et al. (2016) in their systematic review and meta-analysis, showed the increasing effectiveness to prevent injury with each new and successive IPP. The formalised programmes started as the F-MARC Bricks, progressively evolving into the FIFA 11 and finally in their most effectual incarnation yet as the FIFA 11+. The programme benefited from both qualitative and quantitative research involvement from experts and players. Displaying a progressive and objective improvement with evolution.

The pervasive predicament with interpreting main results from multi-sports systematic reviews consisting of various exercise intervention is heterogeneity. Systematic reviews in this field regularly pool data and present meta-analyses results with substantial (I^2 = 75 to 84%) and statistically significant ($P < 0.001$) heterogeneity without attempts to address this (Al Attar and Alshehri, 2019b, Leppanen et al., 2014), while previously some researchers omitted to comment on heterogeneity assessment sufficiently (Al Attar et al., 2016, Rossler et al., 2014, Smyth et al., 2019). This systematic review covered seven different sporting codes; a large variance in population, interventions, outcomes, and time periods potentially resulting in marked heterogeneity. The factors that proved decisive were the decision to investigate the shoulder specifically and to include only RCTs, as they were the most significant.

Attempts to stratify the main findings to further explore the factors that are potentially responsible for the effect, like the most effective components of the programmes, are regularly met with excessive heterogeneity (Dijksma et al., 2020, Huang et al., 2020, Leppanen et al., 2014, Sugimoto et al., 2015). An assumption may exist that earlier studies did not address heterogeneity adequately due to deficient reporting requirements, but this is not the case as some earlier systematic reviews are of high quality (Hubscher et al., 2010). The seminal work of Higgins et al. (2003) has been published and cited from the early 2000s providing no reasonable explanation for contemporary literature to inadequately report or address heterogeneity.

Some authors suggest that an $I^2 < 50\%$ is a cut-off point when considering the feasibility of pooling or merely stating that the heterogeneity was too substantial for pooling (Caldemeyer et al., 2020, Dijksma et al., 2020). This method does not consider the statistical significance of the inconsistency nor does it use different statistical approaches. The preferred approach in injury prevention is to use a random-effect statistical model and then perform sensitivity analyses, subgroup analyses, or meta-regression in an attempt to identify the cause of heterogeneity in the meta-analyses (Faude et al., 2017, Petushek et al., 2019). This study followed the literature recommendations and made the *a priori* decision to utilise the random-effects model with a pre-planned sub-group and sensitivity analyses.

The systematic review of Lauersen et al. (2014) serves as an exemplar in the field. The study investigated exercises' effectiveness to prevent lower limb and overall injuries. All meta-analyses, except the stratification of strength training, stretching, and overuse injuries, revealed statistical and substantial heterogeneity. The literature is divided when considering whether performing and including meta-analyses with such high levels of heterogeneity infringes research ethics irrespective of warning readers to the results' insignificance (Melsen et al., 2014). Their study's main findings generated a statistically significant and substantial inconsistency of $I^2 = 70\%$ ($P < 0.001$), and their main results were statistically insignificant. Keep in mind that the study had a wide variance in PICO and conservative risk of bias scoring.

Heterogeneity should be considered in the context in which the study was done. Lauersen et al. (2018) in their follow up systemic review and meta-analysis, solved their heterogeneity problem by investigating only one component of IPPs, namely strength training. The result was based on their previous research and improved their approach by including pre-planned meta-regression. Thus, by reducing the dissimilarity in at least one of the PICO components, the certainty of the results improved tremendously. The strict focus on heterogeneity ensures that research does in fact compare apples with apples. Researchers should notice the marked improvement in the methodology, as the authors addressed limitations espoused in the previous systematic review.

However, despite the emphasis on comparing homogeneous factors, the context and clinical reasoning remain of utmost importance. When comparing apples to apples, make sure you are in an apple orchard. The presence of heterogeneity with any pooling is expected, and with a vastly broad PICO, low heterogeneity is practically a mathematical impossibility (Higgins et al., 2003). The main question is then, to what extent it influences the results? This systematic review performed comprehensive sub-group analyses to address this issue and used best-practice guidelines to uncover the truest effect size possible. Statistical significance of heterogeneity was placed in direct juxtaposition with the quantity in the summary of results to enable comparison.

When interpreting a systematic review with meta-analysis in injury prevention comprising of a broad PICO, the recommendation to the reader is to employ *caveat emptor.* The interpretation of results requires some statistical and contextual knowledge and is likely to be not as easily disseminated to the lay population as assumed, despite using RR values that can easily translate into percentages. Systematic review research may benefit from providing a lay summary that is peer-reviewed, as part of the dissemination strategy and form part of the additional documents attached to the publication.

This study attempted to rectify this problem by providing enough background information to contextualise how heterogeneity affected the results and generated a summary of results that enables a simpler comparison for knowledgeable readers. Considering the literature mentioned above, it seems unlikely that the sporting population which is targeted will have the skill and knowledge to critically assess the results and prevent erroneous inferences. The ultimate responsibility to ethically present the results with adequate background information lies at the feet of the researchers.

The findings corroborate overall injury prevention estimates and specific location prevention estimates such as those found in the knee. The results indicate sizeable effects comparable to outcomes in the literature as the results are statistically significant with the heterogeneity resolved. The practical significance for practitioners should be evident as athletes can spend as little as 10 minutes per training session to prevent severe injury burden to the shoulder. The prevention of half of all shoulder injuries sustained is of tremendous clinical significance to all athletes and coaches. The sporting community requires serious contemplation to justify a stance for non-implementation.

5.4 The prevention of upper extremity injuries

The secondary meta-analysis found that slightly more than a third of upper extremity injuries, including injuries to the shoulder, upper arm, elbow, forearm, wrist, and hand, are preventable with exercise interventions. An important *caveat* is that substantial and statistically significant heterogeneity was detected during the meta-analysis that limits the generalisability of the finding. Supplementary sub-group analysis and sensitivity testing for the upper extremity are beyond this dissertation's scope, as the primary focus is on shoulder injuries. The results are therefore to be interpreted with caution.

The magnitude and direction of effect indicate sufficient similarity with the shoulder specific results to justify this meta-analysis's inclusion. The heterogeneity falls just outside the range for moderate but shows a low P-value indicating that the cause of the heterogeneity may be clinical (Fletcher, 2007). The I^2 statistical cut-offs are rough guidelines, and further investigations and analyses can overcome them (Barili et al., 2018). The heterogeneity should be contextualised within the subject field as pharmacological effectiveness reviews, on which reporting standards are based, will produce much less inconsistency than injury prevention effectiveness reviews.

The magnitude of the outcomes are not as large as those reported by Al Attar and Alshehri (2019a) in their unpublished study investigating upper extremity injury prevention in goalkeepers. Their findings report a decrease in more than half of all upper extremity injuries, indicating comparability to the expected effects found in lower extremity IPPs. The programme has developed from a solid research base and utilised the same implementation framework as the well-proven FIFA 11+ programme (Ejnisman et al., 2016). The indications are there to remain cautiously optimistic until publication and peer-review confirm the results. There are no other systematic reviews to compare the findings to, and as such comparison to lower extremity results is indicated.

The systematic reviews addressing specific single locations such as the knee can be compared to this study's shoulder results in the primary meta-analysis. Simultaneously, in the secondary meta-analysis, the upper extremity results are more comparable to the pooled results of the lower extremity in the literature. The comparability is justified as an investigation of a single location or body areas such as the shoulder or knee will comprise more homogeneous studies than can be expected of the upper extremity or the lower extremity. The differences in participants, interventions, study durations, outcomes or sample sizes are less for a single bodily area than for a whole extremity.

Rossler et al. (2014), in their meta-analysis investigating injury reduction in child athletes, found a reduction of almost half of lower limb injuries with a heterogeneity (I^2) score of 50%. The results associated with child and youth IPPs indicate a more significant effect in this population than in adults (Faude et al., 2017, Rossler et al., 2014, Rossler et al., 2018). Hubscher et al. (2010) in their systematic review, found a lower effect which included adolescents to young adult athletes but still produced a sizeable preventative effect of approximately 40%.

In their meta-analysis, Al Attar et al. (2016) found that the F-MARC IPPs could prevent approximately a quarter of all lower limb injuries in soccer players. The study, regrettably, did not provide any heterogeneity measures. Al Attar and Alshehri (2019b) found that slightly more than a quarter (29%) of lower limb injuries could be prevented with exercise intervention in their meta-analysis of meta-analyses. Their lower limb analysis's heterogeneity was considerable and thus thoroughly identified in this study's upper extremity analysis.

Even with the substantial heterogeneity, the results are comparable with the verified effect documented for the lower extremity in the literature. The effect is superior for those reported for adults, but less than those reported for child and adolescent athletes. The results are statistically significant, and with the direction and effect comparable to existing evidence, the practical significance for the healthcare community is evident. A potential reduction of a third of upper extremity injuries can be considered clinically highly significant to the sporting community.

The investigation into the upper extremity is challenging as it necessitates a change in injury classification, adaptation in injury reporting, modification or development of specific programmes and the limited validated functional test for the area. The foreseeable pattern is that the overwhelming majority of upper extremity data will still come from incidental data. The shoulder will benefit from more specific and focused research, as programme development is grounded in an established literature base. The consequence of shoulder specific research is that it could lead to extrapolation to the whole upper extremity, which intuitively seems unsuitable as the conventional pattern dictates that lower extremity research is extrapolated to the knee.

5.5 Acute *versus* overuse shoulder injury prevention

A recent systematic review noted that a lack of data precludes any generalisation of prevention strategies' effectiveness in averting overuse injuries (Brunner et al., 2019). The finding was made despite the systematic review of Lauersen et al. (2014), which showed that overuse injuries were more successfully prevented than acute injuries in the lower extremity. Moreover, the second review by Lauersen et al. (2018) revealed that strength training is superior to NMT and can prevent two-thirds of acute sports injuries and a third of overuse injuries.

This systematic review found that IPPs induce a slightly better prophylactic effect on acute shoulder injuries than on overuse injuries in the upper extremity. A quarter of acute shoulder injuries could be prevented compared to a comparable but slightly less than one-fifth of overuse shoulder injuries. Both subgroups' results were statistically significant, which allows for correlation and further discussion. The heterogeneity in both sub-analyses was moderate; however, overuse injuries' heterogeneity was statistically insignificant and thus unimportant.

The finding is analogous with other studies indicating a less preventative effect for overuse injuries (Lauersen et al., 2018). The result is unsurprising as it has been well established that studies are designed to primarily target acute injuries (Klugl et al., 2010, McBain et al., 2012a). The outcomes are expected to improve as the focus shifts to preventing more overuse injuries in general and in the upper extremity specifically. Further research is required to investigate whether theoretically similar results can be expected from a single IPP to address acute and overuse injuries equally or whether the type of intervention will always dictate the superiority of one over the other.

The answer may lie in a more rigorous investigation into the mechanisms that produce the prophylactic effects. The information on the mechanism of action is limited, and current strength training provides the best departure point from which to speculate from as the evidence base is the strongest. As mentioned in the literature review, most IPPs do not meet the requirements for strength training, nor for the performance period required to achieve an effect. The mechanisms cannot be precisely the same but should be similar enough to develop testable theories for injury or prevention. The key may be to gain a better understanding of how the interactions work rather than a searching for alternative mechanisms.

Theoretically, it is difficult to suggest whether it is less complex to prevent an acute or overuse injury. The cumulative stress hypothesised to cause overuse injuries (Clarsen et al., 2015, Fuller et al., 2006, Neil et al., 2018) is proposed by McBain et al. (2012b) to be brought into equilibrium by IPPs performance. Yet, Dijksma et al. (2020) reported an increase in injuries with the increasing load, and Sugimoto et al. (2015) found that adding other components to IPPs could reduce programme effectivity. The inference is that an undefined sweet-spot exists within an unknown range for tissue stress that could be enlarged with IPPs. The existence of a goldilocks region for IPPs seems plausible.

The IPPs stimulating an effect or load that falls outside the range will either produce no effect on the lower end of the spectrum or cause overuse injury on the higher end of the spectrum. Increased overuse injuries are reported in one study that implemented the FIFA 11+ which is one of the few studies reporting an adverse effect (Longo et al., 2012). The theory runs parallel with the workload theory initially proposed by Gabbett (2016), which was later refined to state that acute spikes in workload rather than chronic high loads are responsible for overload injuries (Gabbett, 2020). The influence of workload may explain why acutely adding an IPP can cause increasing injury rates while adding components to IPPs results in less effectivity.

The calls for the research community to recommit to investigating overuse injuries and providing reportable data is topical (Bahr et al., 2020). The proportion of included studies designed to target overuse injuries and complaints in this review is pleasantly surprising, as four studies could be included. This type of research addresses a material need in the field and attempts to close the gap in the literature as the shoulder suffers from a high prevalence of overuse injuries in sport (Aasa et al., 2017, Cools et al., 2020, Schorn et al., 2018, Struyf et al., 2017).

Local injury surveillance data indicates that the second principal cause of injury in cricketers is overuse mechanisms, with almost a quarter of injuries sustained in the upper extremity (Stretch, 2003). The sub-group meta-analysis indicates that an IPP implemented locally can prevent all or most of the reported overuse injuries in South African cricketers who were investigated, signifying the high level of clinical significance and practical application of this finding.

5.6 Shoulder specific IPPs to prevent shoulder injuries

The sub-group analysis between shoulder specific and non-specific programmes revealed an unexpected finding. The shoulder specific meta-analysis result revealed moderate and statistically significant heterogeneity. Despite the effect size showing similar directions, the results were statistically insignificant. Thus, a quantitative comparison between the two sub-groups would not be possible.

Nevertheless, the results of the non-specific programmes proved decisive and showed low and statistically insignificant heterogeneity, meaning they are unimportant. The findings can be interpreted with a high level of certainty. Interestingly, the direction is similar to all other findings, but the magnitude of the effect is one of the largest of all the sub-analyses and statistically significant. Proving that half of all shoulder injuries were prevented by either not targeting or incidentally targeting of the shoulder by IPPs.

The approach recommended by Mugele et al. (2018) should be highlighted here. The distinct components of proven IPPs should be individually investigated for their effect on shoulder injuries. The reduction to only the most ‘effective’ exercises would reduce the programmes’ application time and may improve execution and compliance. Multimodal shoulder programmes can be designed from the effective components; this approach is advocated by Lauersen et al. (2014).

A newly published systematic review may in part answer the thought-provoking finding as to why lower extremity programmes are effective in the prevention of shoulder injury. Richardson et al. (2020) found that muscle activity and recruitment is affected by the trunk and lower extremity movement. The authors found that lower extremity activities such as stepping can enhance scapular stabiliser activation, optimise trapezius muscle recruitment and reduce rotator cuff load. The findings of this systematic review corroborate the physiological and neurological effects from an outcome level. In-depth analysis could confirm whether this was indeed one of the mechanisms of action facilitating the prophylactic effect of IPPs.

The inference is that programmes that target the shoulder are not sufficient in terms of load or volume to cause adaptive changes in the shoulder. This review collated the volume in repetitions and time providing an estimate for the first time on the training volume applied to shoulder IPPs. The evidence base for comparison is lacking for shoulder load and volume. The research community is encouraged to utilise this data to determine effective baseline load and volume for the shoulder. The confirmation of a dose-response to IPPs implies that the principal mistake in designing shoulder programmes is that we are underdosing (Lauersen et al., 2018).

5.7 Upper extremity *versus* lower extremity dominant sports

The prophylactic effect in upper extremity dominate sports revealed unimportant heterogeneity and a statistically significant preventative effect of almost a quarter of shoulder injuries. The effect in the lower extremity sports is almost twice as high as the upper extremity dominate sports, but the results should be interpreted with caution as substantial and statistically significant heterogeneity exists.

The similarity of upper extremity sports showed less clinical diversity than that of the lower extremity sports. The upper extremity sports included a mixture of non-contact sports, namely baseball, tennis, and volleyball, with handball the only contact sport.

The lower extremity sports included a contact sport, namely football and collision sports, namely rugby and Australian football. The diversity between the lower extremity dominate sports makes comparison impractical.

However, the effects in the upper extremity sports can be investigated further. The results showed a smaller effect magnitude than the primary analysis. The explanation could be deduced from the focus of the studies. Slightly more than a third of the studies included in this subgroup actually targeted the shoulder; while a few had an indirect focus on the shoulder through emphasising upper extremity prevention. Most studies included shoulder exercises incidentally and had no expressed aim to prevent shoulder injuries. This aligns with the reasoning of shoulder specific programmes and indirectly indicates that the current programmes are ill-suited for shoulder injury prevention.

5.8 Study designs and perspectives on injury prevention

RCTs' excess utilisation in sports injury research is well recognised in the field (Vriend et al., 2017) and not unforeseen as it is the gold standard for health interventions (Mitchell et al., 2020). This systematic review only included RCTs with the significant variation that cluster randomisation was utilised. The difference lies in the randomisation protocol, where cluster designs randomise groups (clusters) and RCTs randomises individuals (athletes). The included studies were approximately half RCTs and half cluster RCTs, each enabling a large enough sample for a robust sub-group analysis.

Unexpectedly, the sub-group analysis between the two types of RCT designs showed the most significant results of all the analyses. The preventative effect in the RCTs showed that half of all shoulder injuries could be prevented by exercise intervention, while the results of the cluster RCTs were statistically insignificant. The discrepancy in the results is conceivable since the majority of the cluster RCTs are large scale studies that incidentally produced shoulder data, whilst the RCTs are smaller targeted studies with a specific aim such as the prevention of shoulder injuries.

A typical drawback of a RCT in comparison to a cluster RCT is smaller sample sizes. Systematic reviews indicate that most studies show a prophylactic effect; however, the results are statistically insignificant in 50% of the cases (Leppanen et al., 2014). This study revealed that the cluster RCT sample sizes' were larger by a factor of approximately five. The randomisation of groups such as teams are complex with the standardised RCT's randomisation, and thus cluster randomisation is easier to use if multiple teams in an organisation or sporting code are studied. Nevertheless, the reported reason to use cluster randomisation is to prevent contamination and yet the ease of use is not referenced.

The literature preaches that the optimal study design in injury prevention remains a RCT (Emery et al., 2015b), but adaptations are necessary when investigating large groups as in teams. Various forms of RCTs have proved practical in a team environment, but none more so than the cluster RCTs. Cluster randomisation can eliminate contamination bias but results in a high drop-out rate, resulting in valuable data being lost and the induction of its own bias (Emery and Pasanen, 2019, Rossler et al., 2018). Cluster adjustment is necessary as outcomes are more similar within each cluster than between clusters resulting in non-independence of data and overestimated statistical significance (Emery, 2007, Nielsen et al., 2020b).

A cluster RCT remains a precarious design as it can reduce contamination bias but increases the drop-out rate, as groups rather than individuals, tend to withdraw (Mugele et al., 2018). The paradoxical aspect is that if most studies already suffer from insufficient blinding of participants, how much more contamination can occur? The main reason for applying cluster randomisation is not achieved in most studies. The use of cluster RCTs seems like a pragmatic decision as to randomise a single team into two groups will not allow for a coach-led implementation of the interventions. The process would be more complex and time-consuming, but these obstacles can be overcome.

An example is provided on how to overcome the issues of pragmatic implementation. The use of a placebo control or a superiority trial designs would work best, and the teams would be split into two groups for warm-ups with one or two selected players in the group being the delivery agents or fidelity monitors, depending on the implementation framework. The example above is simple to execute but would be complex to implement and may be criticised for its complexity. Researchers' concern is to keep behaviour changes as simple as possible to prevent a reduction in adherence. The problem may not be adherence as such, but the perception by each level of the IPPs.

The research community has a static perspective influenced by the traditional approach, indicated by the systematic reviews highlighting the same concerns *ad* *infinitum*. These perspectives can be expanded by education (better training for researchers) or by a change in thinking (paradigm shift). The sporting community has its own static perspectives on injury prevention influenced by experience and past results. Any change will be met with some resistance, and the amount of the resistance depends on the participants' perspective. Will reviewers keep on excoriating compliance levels if the athletes find the programmes enjoyable, stimulating, or challenging? The design of studies may want to start the process there; if not, the field is in for a long road of constant education until the practice becomes the norm.

Other study designs have not been ideally suited to the task. Cross-over study designs may reduce bias but require that the participants go through a wash-out period before acting as their own control group, making RCTs a more pragmatic design for training related interventions (McBain et al., 2012b). The application of cross-over designs will only be feasible if the wash-out period's natural progression is confirmed, as the option to induce wash-out would be unethical.

Vriend et al. (2017) mentioned that no study was found to use Solomon’s four-group design where four groups are used to control for the effect of performing a pre-test. The Solomon’s four-group design can diminish the risk to internal and external validity, and a problem is that the design is resource-intensive, complex and requires advanced statistical analyses (LavanyaKumari, 2013). This design is not recommended for small scale studies but may work for multi-geographical studies with access to the necessary resources.

The use of alternative RCT designs can improve the drawbacks accompanying the current design. The use of superiority trials (Al Attar et al., 2017), sham or placebo programmes (Attwood et al., 2017) and the rarely utilised three armed design could reduce the performance and detection bias so widely associated with the field. The ideal RCT would utilise a three-arm superiority trial design with the use of an implementation framework like RE-AIM (Glasgow et al., 2019).

5.9 Components of shoulder prevention programmes

Two of the secondary aims of this systematic review were to collate and synthesise the components of shoulder IPPs in order to provide an overview of current practice. The components utilised in the research indicate that a quarter of programmes consist of functional exercises, and an equal fifth of programmes consist of strength and multimodal components. The minority components further include approximately one-tenth of mobility, plyometric, proprioception and lastly flexibility. The most effective component remains elusive in the upper extremity, similar to the lower extremity (Leppanen et al., 2014).

The components that comprise IPPs in this review are different from those commonly identified in the literature, as strength and balance training generally overshadow all other components (Vriend et al., 2017). A decade ago, McBain et al. (2012a) indicated that strength and power studies were on the rise; this is seen for the strength components but not for the power components. The lack of plyometric components is unexpected, as the dynamic nature of the shoulder requires explosive movements and rapid deceleration (Cools et al., 2015, Cools et al., 2020).

The plyometric component contribution may be underestimated as Leppanen et al. (2014) described that half of their effective multimodal exercise components included strength and power. The majority of their multimodal exercises included proprioception, coordination, power and strength components. The proviso with multimodal components is that the specific components have to provide better results objectively and the theorised ‘more is better’ assumption has to be tested conclusively.

The literature has produced evidence that single components programmes are more effective than multimodal components programmes (Lauersen et al., 2018), and is unable to have an adverse interaction with other components (Petushek et al., 2019, Sugimoto et al., 2015), and have no reported harmful effects unlike multimodal programmes (Attwood et al., 2017, Dijksma et al., 2020). The investigation and possible comparison between a single component versus a multi-component programme in a systematic review may provide better more on the optimal structure.

The shoulder's functional exercise component includes balancing on the arms in a bridge or throwing components not vigorous or weighted enough to classify as strength or plyometrics. This can provide a disproportional representation of the functional component as this classification typically includes incidental shoulder loading through weight-bearing without weight shifting. The components of strength and multimodal exercises are proportionally twice as much as the other exercise components, which align with the literature indicating the superiority of NMT and strength training.

The advocating of upper extremity static stretching by McCrary et al. (2015) was only embraced by one included study, which included the most stretching exercises (Sakata et al., 2019). The study showed a positive effect, but it is unclear whether the outcome can be attributed to static stretching as the largest emphasis was on the mobility component. Reviews have by and large shown stretching to be ineffectual in the prevention of injury (Dijksma et al., 2020, Leppanen et al., 2014, Lauersen et al., 2014); nevertheless, one point that needs to be conceded is that the studies are older, and may have suffered from poor methodological quality.

The preventative effect is hypothesised to be a result of the sum of its parts. The literature is unclear whether it is possible or feasible to determine which part of IPPs is the most effective and which part does not affect injury risk (Leppanen et al., 2014). The reasoning may initially appear to align with the complex system approach as it may be likely that the total effect is probably achieved *via* interaction between the components. The answer may not lie in an absolute but somewhere on the spectrum as other reviews have started to identify 'superior' components (Lauersen et al., 2014, Lauersen et al., 2018). The research community's responsibility is to test these theories objectively and start with unsubstantiated mainstream opinions first.

The primary ethical responsibility is to determine whether any adverse effects occur with the application of IPPs. The unreserved utilisation of NMT multimodal exercise programmes may not be as safe or beneficial to the participants as touted to be. The range (Goldilocks zone) exists where if stimulation is too limited IPPs do not appear to be effective, this is observable when compliance is low (Pas et al., 2020). On the other hand, if the acute load is too high, it can be harmful and increase overuse injuries (Attwood et al., 2017, Dijksma et al., 2020). The other argument is that if the components are not beneficial, they waste time and resource (Petushek et al., 2019).

The interaction between the components requires investigation from a complex systems approach as indications are surfacing, where individual components' inclusion reduces the programmes' total effectiveness (Sugimoto et al., 2015). The multimodal programmes are theorised to limit beneficial exposures, and the approach to include everything can possibly lead to over cumbersome programmes which the sporting community will never adopt (Lauersen et al., 2014).

In this systematic review, more studies included CKC exercises than OKC exercises. The literature reports that electromyography activation of the shoulder is superior with closed chain exercises revealing alignment of research and practice (Pozzi et al., 2019). However, the problem is not as simple as a recent review indicates, as muscle synergies are optimally stimulated in both open and closed kinetic chains, depending on the required action performed by the upper extremity (Mendez-Rebolledo et al., 2021).

The deficit or muscle imbalance model is associated with this finding as specific deficits may occur in both open and closed kinetic chains, resulting in a compensation pattern for directional and specific actions. Further investigation into the kinetic chain influence in effectiveness studies is encouraged, as the most evidence is produced in efficacy studies at present.

5.10 Quality of included studies

The quality of the studies was moderate, with ranges from high-quality to low-quality. This was unanticipated as the *a priori* decision to only include RCTs was made to prevent selection bias when studies were appraised before inclusion and to keep the methodological quality high as RCTs are high level of evidence. The inclusion of only cluster RCTs and RCTs was similarly performed in another recent review (Dijksma et al., 2020). The pre-planned decision was made to include all eligible studies and to perform a critical appraisal after exclusion, which is an acceptable method to reduce selection bias (Leppanen et al., 2014).

The review included no study that was entirely free from bias. The same finding was reported in another review (Dijksma et al., 2020), where 80% of the included studies which were also cluster RCTs and RCTs studies revealed a high-risk of bias. Only a third of studies included in this review revealed a high-risk of bias when using the 50% score as a cut-off point. Although consisting of a moderate quality of studies, the review had good quality in the context of the accepted norms in the field and was comparable to reviews done by others (Petushek et al., 2019).

The quality rating can purportedly be tempered by the fact that unsatisfactory reporting standards may be partly responsible for the low scoring. The same argument was proposed by Hubscher et al. (2010) that underestimating the quality was due to the lack of objective and transparent reporting instead of inadequate study designs or methods. The argument may be valid, as this systematic review displayed an inordinate number of unclear designations in the critical appraisal.

However, an argument of inadequate reporting can still not be acceptable at this stage in the development of the field, with so many authors claiming high academic meticulousness (Emery and Pasanen, 2019). A recent systematic review can attest to the same problem of 'secretive' reporting, and the recommendations sound like an echo (Mugele et al., 2018). Indicating that researchers do not meticulously inspect systematic reviews' recommendation before implementing an injury prevention study.

Reporting guidelines are available and a necessity in producing high-quality trial. The guidelines by CONSORT and Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) are widely supported (Emery et al., 2015a), and nine included studies claimed they followed the CONSORT guidelines. Although the inclusion of the checklist is not a common prerequisite for publication, the actual inclusion of the checklist was only done by one study (Finch et al., 2019).

The decision to exclude non-randomised studies is bolstered by other reviews indicating that these studies' reporting standard is unacceptable or may have had a negative effect on their results (Leppanen et al., 2014, Mugele et al., 2018). Surprisingly the review by Dijksma et al. (2020) found that the risk of bias was considerable, with 12 of the 15 studies indicating high risk from their cluster RCTs and RCTs. In this systematic review, only five studies were under the threshold of 50% and could thus be classified as high-risk of bias.

Leppanen et al. (2014) commented on the improvement of the methodological quality post the 2000s and implied that a progressive improvement had occurred from the past to the present. Indeed, this first part was evident in the study by Wedderkopp et al. (1999), which showed a very restricted approach to reporting. The striking thought is that the study is viewed by contemporary standards as low quality; however, it was deemed high quality at the time of publishing. The study was progressive in that it included upper extremity data for a balance board intervention, which was not standard practice at the time. Nevertheless, this study did not find a pattern of improved reporting annually, as suggested by the literature.

Selection, performance, detection, and attrition bias is a common phenomenon in injury prevention research, affecting the methodological quality of studies (Emery and

Pasanen, 2019, Leppanen et al., 2014). This review's sensitivity analysis revealed the influence on the effect size is considerable, and if not controlled can lead to inaccurate inferences. These factors affect internal validity dramatically, and an examination of which produced the most significant influence will be both noteworthy and valuable to future researchers. The presence of risk of bias is known to intuitively diminish the value and quality of the evidence. Researchers utilising more time and resources in the protocol development stage will reap the fruit of their labours when generating their findings.

5.11 Limitations of the studies

Half of the studies included in this review did not report randomisation and allocation concealment sufficiently enough to allow reproducibility. Limited studies produced a retrievable *a priori* protocol or attached it to their supplementary documents at publication. The same problem was described practically *verbatim* by Dijksma et al. (2020), rendering an investigation into possible selection bias challenging.

The likelihood that the protocols do in fact, not exist is relatively low, and the problem may be that the unpublished protocols are difficult to retrieve. This issue can easily be solved by authors attaching the protocol to the published material *via* an online link or as part of the additional documents. The effect of inadequate allocation concealment is that the study has a higher likelihood of generating statistically significant results in comparison to trials with sufficient allocation concealment (Mitchell et al., 2020). The same side-effect is seen in the incorrect application of ITT analysis.

An aspect of selection bias that rarely gets discussed is the refusal to participate proportion. In this review, half of the participants invited to join the studies included in this review refused to participate. The range was highly variable, with some studies indicating very low refusal levels (Andersson et al., 2017, Sakata et al., 2019) to almost no willingness to participate (Attwood et al., 2017, Rossler et al., 2018, Silvers-Granelli et al., 2015). A third of the included studies did not disclose the refusal to participate rate. This should be at minimum be transparently reported in a study and should be provided in a percentage format to allow for comparison at a glance. The consideration to implement a specific IPP should include a perusal of the refusal to participate proportion as this will give policymakers an indication of the feasibility of implementation.

Mugele et al. (2018) found that all their included RCTs suffered from performance bias and detection bias, as blinding participants and outcome assessors were not possible in these studies. Similar results were indicated in other reviews, but it was argued that the problem is inherent in this type of research, and it may not be an appropriate way to assess these type of studies compared to pharmacological studies (Dijksma et al., 2020, Lauersen et al., 2014, Leppanen et al., 2014, Plummer et al., 2019).

The blanket statement cannot justify inferior design or limited efforts, as some researchers actively endeavour to limit performance and detection bias and were successful (Al Attar et al., 2017, Attwood et al., 2017). The two successful methods used in both these cluster RCTs were to perform a superiority trial with an extra warm-down intervention (Al Attar et al., 2017) and to include a sham warm-up programme (Attwood et al., 2017). There are options available to diminish the effect by implementing less utilised designs like Solomon’s four-group design that can overcome these limitations.

High-quality studies are brought into disrepute when the experimental groups receive more attention and effort than the control groups. A phenomenon where the intervention groups are visited twice as much as the control groups is a regular occurrence. The research team's reasons may be well-intentioned to keep high compliance levels but bring beneficial results into question (Al Attar et al., 2017, Andersson et al., 2017, Sommervold and Osteras, 2017). The assumption exists that experimental groups’ compliance will wane as they are tasked to do more.

Surprisingly, the problem lies not with the active intervention group, but with the control groups’ compliance and an included study found a total lack of compliance in the coaches of the control groups (Sommervold and Osteras, 2017). Several studies revealed a higher drop-out rate for the control group, as the burden of the extra workload with no perceived benefits demotivates all involved, mainly as the groups are not effectively blinded to their allocation (Al Attar et al., 2017, Attwood et al., 2017, Hislop et al., 2017, Osteras et al., 2015, Rossler et al., 2018, Sommervold and Osteras, 2017).

The performance of regular unannounced visits for both groups equally remains an effective strategy to improve compliance and reduce drop-out during the study. The finding in this review was that the control group had a 2% higher drop-out rate on average, which in the smaller sample-sized RCTs equates to 54 participants, while in the larger cluster RCTs equates to 201 participants. In comparing the cluster RCTs *versus* the RCTs studies drop-out rate, an unexpected finding was that 10% of the control group in cluster RCTs dropped-out while 13% of the experimental group in RCTs dropped out.

The inference can be drawn that group dynamics may be responsible for this difference in drop-out rate. The cluster RCTs are randomised per team, with the ultimate decision to drop-out in the hands of the coaching and management staff. The logical deduction follows that increased administration without benefit and the potential loss of a competitive edge, which their opponents in the experimental group might have, results in the decision to discontinue.

In contrast to the RCTs studies, where the ultimate decision lies with the individual participant, it seems that the added behaviour change without support, or the extra workload with the intervention brings about the discontinuation. This new aspect warrants further investigation to confirm this phenomenon in practice and requires further scrutiny as it may improve compliance and implementation if the interplay of this factor is thoroughly examined and verified.

One of the fundamental underlying issues which is unexpressed within injury prevention research is the conundrum of how to handle prior IPP performance. Not one of the eligible studies screened for past performance of IPPs; during the interventions three studies specifically reported performance of similar IPPs or extra strength training sessions (Andersson et al., 2017, Olsen et al., 2005, Osteras et al., 2015) in the control groups confounding the effects. The literature provides no evidence-based wash-out period, although it is well established that athletes do get deconditioned during the off-season.

The issue above needs urgent attention as the popularity of IPPs, and the increased awareness make it progressively unlikely that participants would not have participated in some form of injury prevention. The simplest method to investigate the missing element is to monitor the participants after the programme's completion regularly and at specific intervals. The intervals will allow researchers to determine a point where half of the preventative effects have worn off, similar to a half-life in pharmacological studies.

A significant bias, similar to the abovementioned IPPs problem, was that no study examined the potential effect of participation in other sports outside the intervention. An athletic population where the majority are not professionals has a substantial likelihood of participating in multiple sporting codes. The confounding effect is not negligible as the performance in a second sport may act as its own NMT, and the athlete involved cannot be similar at baseline nor during the study. The screening of other sports should be mandatory and should be periodically re-examined, as should all baseline characteristics. The intervention period could run over multiple seasons and during this period winter and summer sports could be competed in, or it may be enjoyed recreationally.

Attrition bias was widespread in the included studies, as 85% suffered from this. The unacceptable drop-out rate and incorrect usage of the ITT analysis were the two main factors inducing attrition bias. Other reviews have found this challenging to deal with and have suggested that it is inherent in injury prevention research (Leppanen et al., 2014, Emery et al., 2015b). The drop-out rate (16.58%) was within the acceptable range for musculoskeletal studies (10% to 20%) indicated by a systematic review (Joseph et al., 2015). Revealing the source of the attrition bias to be found in the usage of the statistical analysis methods.

Aside from the specific limitations above, some general limitations are worth mentioning. There are inherent problems recognised with the self-reporting of injuries (Mugele et al., 2018). The different injury identification procedures namely self-reported, coach reported, internal medical team reported (physiotherapist or athletic trainer), and external medical team reported (physician or special investigation) can influence the findings.

The included studies showed limited interest in explaining or determining the mechanism of action and showed limited inclusion of overuse injuries. The studies that did include overuse injuries then excluded acute injuries from their investigation, providing less information on the effectiveness to deal with both types of injuries for overuse specific programmes (Osteras et al., 2015, Sommervold and Osteras, 2017).

Compliance is a vital factor in order to determine the effectiveness of an intervention (Leppanen et al., 2014). Compliance is typically not reported, and if it is reported, the compliance is unrealistically high (Dijksma et al., 2020), displaying some selective reporting in the studies. An effectiveness study will make a real-world impact if the provision of enabling contexts is provided with robust implementation strategies (Owoeye et al., 2020); compliance being a by-product of this. Studies are honing in on compliance issues and its role in sports prevention research (Nielsen et al., 2020a), hopefully providing reliable recommendations in the future.

5.12 Strengths and limitations og this systematic review

This systematic review adopted a robust search strategy in order to find relevant data and discover incidental shoulder data. The search address limitations in other reviews where too few databases were searched, and more specific search terms for sporting codes and injury sites were recommended (Mugele et al., 2018). The review was able to identify and syntheses 15 studies and complete all the aims set out at inception. The systematic process to collate and synthesis was followed as set out by the JBI reviewers manual and PRISMA guidelines. A PRISMA Checklist (Appendix F) is physically included in the study to demonstrate adherence to the guidelines.

The risk of bias across the review was intentionally addressed by first registering the protocol *a priori* in PROSPERO. Secondly, by utilising two independent reviewers for study selection, critical appraisal and data extraction. Thirdly, the risk of bias was addressed by having qualified biostatisticians review the statistical analyses and methodology. Fourthly, the heterogeneity in the results was explicitly addressed, and sensitivity analyses tested the robustness of the effect sizes. Lastly, further formalised testing of publication bias was performed to determine the existence of or any influence on the outcomes.

The field of injury prevention is cluttered with the over publication of systematic review and meta-analyses of the lower extremity without enough primary studies (Brunner et al., 2019). This review addressed a literature gap and did not rework data to replicate an output in a field overloaded with reviews but lacking in meta-analyses. The review provided several sub-group investigations to further explore the results and provide a springboard for future studies that may investigate a specific element in this review.

The inclusion criteria did not limit the sports to upper extremity dominant or overhead athletes (Asker et al., 2018) and provided for the first-time enough literature to provide a synopsis on the subject matter and produce a meta-analysis (Cools et al., 2020).

Acute and overuse injuries were included, which is not traditional for this type of review. The age, sex and sport range was wide enough to provide sufficient external validity to make the findings applicable beyond the included studies. The included studies revealed some methodological weaknesses, resulting in a wide range of quality, bearing in mind that only RCTs were used; this was unexpected.

The results are summarised and paired with the heterogeneity results in the same table. The transparency on reporting heterogeneity is unconventional and is atypical from other systematic reviews. The results of the essential statistical tests are included at a glance in the summary to provide an overview across all the sub-groups and clearly indicate where caution should be applied in the interpretation. Beyond transparent reporting, heterogeneity is adequately addressed within the study. The formalised publication bias testing provided greater certainty with the interpretation of the results.

Some limitations need to be acknowledged in the performance of the systematic review. The method to screen with title and abstract may have excluded some incidental data on the shoulder that could have contributed to the review; although with the robust search strategy, if the studies are incorrectly indexed, they may be irretrievable. The studies investigating surrogate measures were excluded, which could provide interesting results when contrasted against clinical end-points like an injury. The review was limited to exercise intervention which is a small portion of injury prevention and inclusion of policy changes, or equipment inclusion could potentially provide a more holistic overview of upper extremity injury prevention.

Exercises that were poorly described or without visual representation could have been misclassified and resulted in slightly different findings, although to the degree that it could change the overall findings. The inconsistency in the field in terms of effect measures such as RR, IRR or OR makes meta-analysis difficult. The broad-ranging definitions, study designs, populations, statistical methods and outcome measures make studies like this review display high statistical heterogeneity.

5.13 Conclusion of discussion

The discussion interpreted the results and weighed the information sourced from the literature. The findings indicated some interesting results that were unexpected and potentially worthy of future studies. The prophylactic effect of preventing shoulder injuries with exercise intervention is statistically, practically, and clinically significant. The implementation of NMT or strength-based IPP can be prompted with a high level of certainty.

The section on the limitations of the studies disappointingly links back to the Bekker and Clark (2016) observation that injury prevention research is script-based. The formulaic and generic comments resound with the same information and the same recommendations in the systematic reviews over the years. Researchers need to take heed of the recommendations to improve the standard, or we will drop the ball, with the only loser being the athletes.

CHAPTER 6 - CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

6.1 Conclusion

The effectiveness of exercise interventions to prevent shoulder injuries was formerly extrapolated from predominantly lower extremity research. This rigorous systematic review with meta-analyses supports and advocates the use of exercise interventions to prevent shoulder injuries in sport based on evidence pooled from RCTs. The prophylactic effect induced by the performance of IPPs can reduce shoulder injuries by between 23% to 51%. The summary of the aims achieved can be found below in Table 6.1.

The programmes utilised can prevent both acute and overuse shoulder injuries with a slightly greater prophylactic effect in acute injuries. Exercise interventions designed to address the shoulder specifically are not superior to programmes targeting the shoulder incidentally. The prevention of shoulder injuries in upper extremity sports using lower extremity targeted IPPs are effective.

This study forms part of a small but specific portion of injury prevention research that targets the upper extremity and acts as a departure point and yardstick for future studies to compare their upper extremity prevention results. Researchers are urged to thoroughly examine other systematic reviews on injury prevention and implementation before designing a clinical trial.

Table 6.1: Summary of the aims achieved

Primary aim: To find, identify, review, summarise, and synthesise all existing literature on whether exercise interventions can prevent shoulder injuries in athletes from studies that specifically or incidentally investigated the shoulder and upper extremity.
▪ Shoulder injuries: 0.77 (0.65 – 0.91) RR, 95% CI, *P* = 0.013 ▪ Low-quality studies removed: 0.56 (0.38 - 0.82) RR, 95% CI, *P* = 0.002 - Upper extremity injuries: 0.65 (0.56 - 0.77) RR, 95% CI, *P* = 0
Secondary aim: To collate acute *versus* overuse data on shoulder injuries and perform an analysis to provide estimates.
▪ Acute shoulder injuries: 0.75 (0.58 – 0.96) RR, 95% CI, *P* = 0.024 ▪ Overuse shoulder injuries: 0.79 (0.62 - 1.00) RR, 95% CI, *P* = 0.05

Secondary aim: To designate and classify the varieties of exercise interventions affecting the upper extremity included in the injury IPPs, into strength, flexibility, mobility, plyometrics, proprioception, functional or multimodal exercises.			
▪ Strength = 13 (20%)	▪ Flexibility = 4 (6%)	▪ Mobility = 7 (11%)	▪ Plyometrics = 6 (9%)
▪ Proprioception = 5 (7%)	▪ Functional = 18 (27%)	▪ Multimodal = 13 (20%)	
Secondary aim: To describe and categorise the components of the IPP's shoulder specific exercises into a closed or open kinematic chain, and establish an overview of current prevention programmes performed in research for the sporting shoulder.			
▪ Open kinetic chain: 29 exercises (44%) ▪ Closed kinetic chain: 37 exercises (56%)			
RR – Relative risk; CI - Confidence interval; Statistically significance set as P ≤ 0.05			

6.2 Limitations

The meta-analysis enabled the pooling of data across a broad spectrum of populations, sporting-codes, interventions and environments to produce an overall effect estimate that would be valid within the included studies and would allow generalisation beyond. The external validity is restricted to athletes as this review delimited the study inclusion to those training or participating in sports. This systematic review's extensive scope revealed some inconsistencies, particularly in regard to the definitions and outcomes measures utilised. A primary limitation was that heterogeneity will affect overarching reviews, leading to wider CIs and less accurate effect sizes.

The decision to include all eligible studies and not exclude studies based on poor methodological quality reduced selection bias. However, the sensitivity analyses reveal that it had a substantial effect on the magnitude of the effect size and the heterogeneity in the meta-analysis. This decision was shown to have a critical effect on the finding, yet in hindsight, this will not be amended. The limitation placed on the study by this issue can be overcome by including robust sensitivity testing and including a pre-planned analysis where the low-quality studies are removed.

6.3 Implications for practice

High-quality systematic reviews have proven the effectiveness of exercise intervention to prevent lower extremity and overall injuries. This review has validated that a similar prophylactic effect can be expected in the upper extremity. The sporting community is encouraged to implement IPPs to prevent shoulder injuries with a high degree of certainty. The introduction of IPPs to replace the usual warm-up is effective, low-cost, with implementation successful over various sporting codes and across various environmental contexts to prevent shoulder injuries.

IPPs for shoulder injury prevention can be directly adopted from existing and available programmes, despite their focus on the lower extremity. The introduction of shoulder specific programmes should be evaluated against known and proven IPPs with a sound research foundation such as the FIFA 11+. The foundation can be adopted with certain adaption recommended if further targeted research becomes available. In the absence of more component specific research, strength-focused and NMT programmes may be superior IPPs.

The sporting community is advised to further investigate the FIFA 11+ shoulder IPP with caution. Clinical practitioners should be judicious in selecting the type of IPP to implement, with the majority of the programme consisting of NMT or strength exercises preferable. The most prudent recommendation to clinical practitioners is to implement IPPs, if not yet done. The high benefit to cost ratio and low-risk element make non-implementation irrational in light of the strong evidence favouring IPPs. Collaboration is paramount between the research community, sporting community and medical community to drive implementation, sustained execution, delivery and adoption.

6.4 Recommendations for Future Research

Future studies should endeavour to improve their inherent validity by reducing the potential risk of bias and adhering to transparent reporting guidelines. The first step starts with a protocol that is developed and published *a priori*. The protocol should be easily accessible and preferably attached as a supplementary document. The amendments should be reported together with their reasons.

The reporting guidelines utilised should be mentioned in the study's body and should include a filled-out checklist as an appendix or additional documentation. Included should be a PRISMA, CONSORT, SPIRIT or other relevant consensus checklists to improve reporting standards. Supplementary online documents should be used to overcome the inherent space limitations placed on authors by journals to provide the research community with enough information to appraise and reproduce the study critically.

A pertinent consideration is the inclusion of the number of participants who refused to participate in the study and provision of the data as percentages. This is extremely important for injury prevention research. When half of a sporting community for example chooses not to implement the programme, it reflects the programmes ability to produce real-world outcomes. The confusion around efficacy studies *versus* effectiveness studies is evident in insufficient preliminary buy-in from the sporting community reflected in the refusal to participate.

Similar to the refusal to participate, the dropout-rate should be adequately disclosed with the reasons provided. This proposition is not new or revolutionary but fundamental to evaluate if an ITT or PP analysis was performed correctly. The reasons should adequately explain why the drop-out occurred. A further suggestion is to include the drop-out rate as a percentage for each group can be used to determine at a glance if an unequal rate exist, which would indicate underlying bias.

ITT and PP analyses should ideally both be included as a pre-planned method of analysis. Injury prevention research could benefit from PP analyses as compliance is a material problem that PP analyses do not suffer from; the only drawback is that PP analyses may overestimate the effect. Typically, ITT analyses are plagued by missing data, resulting in underestimating the effect to such a degree that no finding can be produced. In such a scenario, the use of a PP analysis would indicate the effect's direction, although the magnitude may be inaccurate.

Inclusion of both acute and overuse injuries in injury prevention is advised to reduce reporting bias and should become accepted as a minimum standard. Studies are encouraged to report re-injury as a sub-classification and are challenged to include detection for subsequent injuries. The vital first step is to document and classify injuries comprehensively as future research may develop from the extracted data. The primary study may not utilise the recorded incidental information but this data could at a later stage be mined by other researchers. The prevention mechanisms and the injury mechanisms should be investigated in light of the type of injuries sustained.

Self-reported measures could reduce the ability to differentiate between acute and overuse injury as recall bias could play a role in inaccurate reporting. An internal control check can be prudent to improve the precision of injury classification and recording. The checks could include in-house confirmation of diagnosis by medical professionals, confirmation by external medical professionals, or at least by qualified research personnel during the data collection process.

The intervention exercises are, at times poorly described resulting in misclassification or non-reproducibility. Authors are urged to include a visual representation of exercises in either still photography, animation or videography in a supplementary document or to provide online access to the material. Some studies do not fully disclose the exercises as the programmes are proprietary products from commercial programmes and applications. This causes an ethical dilemma as the programme cannot be fully appraised or reproduced. One solution may be to run a comparison trial between a known programme such as FIFA 11+, a sham programme, the proprietary intervention and a control group.

As IPPs become more popular and mainstream, it is fundamental that researchers screen athletes for previous performance of IPPs and provide detailed information on the type, intervention volume and duration. The literature provides no known wash-out period for IPPs, and although it is theorised that the effects wear off, the duration of which is uncertain at this time. Various authors have recommended that the next logical step is to evaluate the components of IPPs for their effectiveness in superiority trials and the follow-up effects measured at intervals after the study has been completed.

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APPENDICES

Appendix A: Search strategies

i) Foundational Keywords and index terms

Level	Foundational Keyword	Text Word	Mesh Term
1 - P	***Sport***	Athlete*	Athletes
		Competition	"Athletic performance"
		Contest*	Baseball
		Exercise*	Basketball
		Game	Canoeing
		Handball	"Cricket Sport"
		"javelin throw*"	Exercise
		jijutsu	"Exercise movement techniques"
		ji-jutsu	Field and Track
		Judo	Football
		Karate	"Games, Recreational"
		Kung Fu	Golf
		overhead	Gymnastics
		"Physical activit*"	Hockey
		"Physical exercise*"	Kayaking
		Pitcher*	Martial arts
		Recreation*	Motion
		Softball	Motor activity
		Sport?	Movement
		Sport*	Netball
		"Tae Kwon Do"	"Para-Athletes"
		taekwondo	"Physical exercises"
		Throw*	"Physical exertion"
		"Track and field"	"Physical fitness"
		train*	"Polo, Water"
		Triathl*	"Racquet Sports"
		Workout	Recreation
		wrestling*	Rowing
			Soccer
			Sports
			"Sports for Persons with Disabilities"
			"Sports Medicine"
			Swimming
			Tennis
			Volleyball
			"Water Sports"

			Wrestling
			"Youth Sports"
2- I	***Exercise intervention***	"balance exercise*"	"Body weight"
		Calisthenic*	"Circuit-Based Exercise"
		"Exercise intervention*"	"Exercise therapy"
		Flexibility	"Muscle Strength"
		Intervenion*	"Muscle Stretching Exercises"
		Isometic*	Proprioception
		Isotonic*	"Range of Motion, Articular"
		"Neuromuscular program*"	"Resistance Training"
		"Neuromuscular training"	Yoga
		NMT	
		"Range of motion"	
		"Strength training"	
		Stretch*	
3 - O	***Prevention***	Decreas*	"Accident prevention"
		Incidence*	"Health Risk Behaviors"
		Injury rate*	"Incidence"
		Prehab*	"Prevention and control" (sub)
		Prevent*	"Primary prevention"
		Prevention	"Program evaluation"
		"Prevention and control*"	"Risk assessment"
		"Prevention program*"	"Risk management"
		"Prevention protocol*"	"Risk reduction behavior"
		"Prophylaxis"	
		"Reduc*"	
		risk*	
4- 0	***Injury***	accident?	Accidents
		dislocation*	"Athletic injuries"
		fracture*	"Cumulative Trauma Disorders"
		injur*	"fractures, bone"
		instab*	"fractures, cartilage"
		"Joint Instabilit*"	"joint instability"
		pain*	"musculoskeletal system"
		problem*	pathology
		"range of motion subluxation*"	"Rotator Cuff Injuries"
		"Shoulder Fracture*"	"Shoulder dislocation"
		"Shoulder Impingement Syndrome*"	"Shoulder Fractures"
		"Shoulder injur*"	"Shoulder Impingement Syndrome"
		"Shoulder Pain*"	"Shoulder injuries"
		strain*	"Shoulder Pain"
		syndrom*	"SLAP Tear"
		trauma	"soft tissue injuries"
			"sprains and strains"

			"tendon injuries"
			Tendons
			"Wounds and Injuries"
5 - L	***Location***	"Collar bone"	"Acromioclavicular Joint"
		Glenohumeral	"Rotator Cuff"
		Gleno-humeral	"Shoulder joint"
		Shoulder*	"Upper extremity"
		"Upper extremity*"	Clavicle
6 - t	***RCts***	"Randomi*ed controlled trial*"	"Randomized controlled trial" (Pub)
		RCTs	
		RCT	

***** Text words and MeSH on each level connected with "OR"

** Each level connected by "AND"

ii) Cochrane Central Register of Controlled Trials in the Cochrane Library (Wiley)

Search conducted on the 05/09/2020 retrieving 1071 results.

Filter: None (unable to filter for Humans)

Search word variations selected

Abstract:ab and Mesh terms:mh searched

Search	Query	Records retrieved
#1	[mh "Exercise movement techniques"] OR [mh "Field and Track"] OR [mh Football] OR [mh "Field and Track"] OR [mh "Games, Recreational"] OR [mh Golf] OR [mh Gymnastics] OR [mh Hockey] OR [mh Kayaking] OR [mh "Martial arts"] OR [mh Motion] OR [mh "Motor activity"] OR [mh Movement] OR [mh Netball] OR [mh "Para-Athletes"] OR [mh "Physical exercises"] OR [mh "Physical exertion"] OR [mh "Physical fitness"] OR [mh "Polo, Water"] OR [mh "Racquet Sports"] OR [mh Recreation] OR [mh Rowing] OR [mh Soccer] OR [mh "Sports for Persons with Disabilities"] OR [mh "Sports Medicine"] OR [mh Swimming] OR [mh Tennis] OR [mh Volleyball] OR [mh "Water Sports"] OR [mh Wrestling] OR [mh "Youth Sports"] OR Athlete*:ab OR Athletic?:ab OR Competition:ab OR Contest*:ab OR Exercise*:ab OR Game:ab OR Handball:ab OR "javelin throw*":ab OR jijutsu:ab OR ji-jutsu:ab OR Judo:ab OR Karate:ab OR Kung Fu:ab OR overhead:ab OR "Physical activit*":ab OR "Physical exercise*":ab OR Pitcher*:ab OR Recreation*:ab OR Softball:ab OR Sport?:ab OR Sport*:ab OR "Tae Kwon Do":ab OR taekwondo:ab OR Throw*:ab OR "Track and field":ab OR train*:ab OR Triathl*:ab OR Workout:ab OR wrestling*:ab	167,784

#2	[mh "Body weight"] OR [mh "Circuit-Based Exercise"] OR [mh "Exercise therapy"] OR [mh "Muscle Strength"] OR [mh "Muscle Stretching Exercises"] OR [mh Proprioception] OR [mh "Range of Motion, Articular"] OR [mh "Resistance Training"] OR [mh Yoga] OR "balance exercise*":ab OR Calisthenic*:ab OR "Exercise intervention*":ab OR Flexibility:ab OR Intervenion*:ab OR Isometic*:ab OR Isotonic*:ab OR "Neuromuscular program*":ab OR "Neuromuscular training":ab OR NMT:ab OR "Range of motion":ab OR "Strength training":ab OR Stretch*:ab	74,594
#3	[mh "Accident prevention"] OR [mh "Health Risk Behaviors"] OR [mh Incidence] OR [mh "Prevention and control"] OR [mh "Primary prevention"] OR [mh "Program evaluation"] OR [mh "Risk assessment"] OR [mh "Risk management"] OR [mh "Risk reduction behavior"] OR Decreas*:ab OR Incidence*:ab OR "Injury rate*":ab OR Prehab*:ab OR Prevent*:ab OR Prevention:ab OR "Prevention and control*":ab OR "Prevention program*":ab OR "Prevention protocol*":ab OR Prophylaxis:ab OR Reduc*:ab OR risk*:ab	687,438
#4	[mh Accidents] OR [mh "Athletic injuries"] OR [mh "Cumulative Trauma Disorders"] OR [mh "fractures, bone"] OR [mh "fractures, cartilage"] OR [mh "joint instability"] OR [mh "musculoskeletal system"] OR [mh pathology] OR [mh "Rotator Cuff Injuries"] OR [mh "Shoulder dislocation"] OR [mh "Shoulder Fractures"] OR [mh "Shoulder Impingement Syndrome"] OR [mh "Shoulder injuries"] OR [mh "Shoulder Pain"] OR [mh "SLAP Tear"] OR [mh "soft tissue injuries"] OR [mh "sprains and strains"] OR [mh "tendon injuries"] OR [mh Tendons] OR [mh "Wounds and Injuries"] OR accident?:ab OR dislocation*:ab OR fracture*:ab OR injur*:ab OR instab*:ab OR "Joint Instabilit*":ab OR pain*:ab OR problem*:ab OR "range of motion subluxation*":ab OR "Shoulder Fracture*":ab OR "Shoulder Impingement Syndrome*":ab OR "Shoulder injur*":ab OR "Shoulder Pain*":ab OR strain*:ab OR syndrom*:ab OR trauma*:ab	335,075
#5	[mh "Acromioclavicular Joint"] OR [mh "Rotator Cuff "] OR [mh "Shoulder joint"] OR [mh "Upper extremity"] OR [mh Clavicle] OR Collar bone:ab OR Glenohumeral:ab OR Gleno-humeral:ab OR Shoulder*:ab OR "Upper extremity*":ab	19,893
#6	[Randomized controlled trial:pt] OR randomized controlled trial:ab	1,111,314
#7	#1 AND #2 AND #3 AND #4 AND #5 AND #6	1071

iii) EBSCOhost: Academic Search Ultimate; Cumulative Index to Nursing and Allied Health Literature (CINAHL) complete; MasterFILE Premier; and SPORTDiscus with Full Text

Search conducted on the 06/09/2020 retrieving 477 results.

The following databases are affiliated with the platform allowing for a combined search:

1. Academic Search Ultimate
2. Cumulative Index to Nursing and Allied Health Literature (CINAHL) complete
3. SPORTDiscus with Full Text
4. MasterFILE Premier

Searched in abstract:(AB)

Limiters selected - Randomized Controlled Trials (Humans unavailable)

Expanders selected - Apply equivalent subjects

Search modes selected - Boolean/Phrase

Search	Query	Records retrieved
S1	Athlete* OR Athletic? OR Competition OR Contest* OR Exercise* OR Game OR Handball OR "javelin throw*" OR jijutsu OR ji-jutsu OR Judo OR Karate OR "Kung Fu" OR overhead OR "Physical activit*" OR "Physical exercise*" OR Pitcher* OR Recreation* OR Softball OR Sport? OR Sport* OR "Tae Kwon Do" OR taekwondo OR Throw* OR "Track and field" OR train* OR Triathl* OR Workout OR wrestling* OR Athletes OR "Athletic performance" OR Baseball OR Basketball OR Canoeing OR "Cricket Sport" OR Exercise OR "Exercise movement techniques" OR "Field and Track" OR Football OR Games, Recreational OR Golf OR Gymnastics OR Hockey OR Kayaking OR "Martial arts" OR Motion OR "Motor activity" OR Movement OR Netball OR Para-Athletes OR "Physical exercises" OR "Physical exertion" OR "Physical fitness" OR "Polo, Water" OR "Racquet Sports" OR Recreation OR Rowing OR Soccer OR Sports OR "Sports for Persons with Disabilities" OR "Sports Medicine" OR Swimming OR Tennis OR Volleyball OR "Water Sports" OR Wrestling OR "Youth Sports"	5,406,034
S2	"balance exercise*" OR Calisthenic* OR "Exercise intervention*" OR Flexibility OR Intervenion* OR Isometric* OR Isotonic* OR "Neuromuscular program*" OR "Neuromuscular training" OR NMT Or "Range of motion" OR "Strength training" OR Stretch* OR "Body weight" OR "Circuit-Based Exercise" OR "Exercise therapy" OR "Muscle Strength" OR "Muscle Stretching Exercises" OR Proprioception OR "Range of Motion, Articular" OR "Resistance Training" OR Yoga	522,198
S3	Decreas* OR Incidence* OR "Injury rate*" OR Prehab* OR Prevent* OR Prevention OR "Prevention and control*" OR "Prevention program*" OR "Prevention protocol*" OR Prophylaxis OR Reduc* OR risk* OR "Accident prevention" OR "Health Risk Behaviors" OR Incidence OR "Prevention	7,946,812

	and control" OR "Primary prevention" OR "Program evaluation" OR "Risk assessment" OR "Risk management" OR "Risk reduction behavior"	
S4	accident? OR dislocation* OR fracture* OR injur* OR instab* OR "Joint Instabilit*" OR pain* OR problem* OR "range of motion subluxation*" OR "Shoulder Fracture*" OR "Shoulder Impingement Syndrome*" OR "Shoulder injur*" OR "Shoulder Pain*" OR strain* OR syndrom* OR trauma OR Accidents OR "Athletic injuries" OR "Cumulative Trauma Disorders" OR "fractures, bone" OR "fractures, cartilage" OR "joint instability" OR "musculoskeletal system pathology" OR "Rotator Cuff Injuries" OR "Shoulder dislocation" OR "Shoulder Fractures" OR "Shoulder Impingement Syndrome" OR "Shoulder injuries" OR "Shoulder Pain" OR "SLAP Tear" OR "soft tissue injuries" OR "sprains and strains" OR "tendon injuries" OR Tendons OR "Wounds and Injuries"	5,454,051
S5	"Collar bone" OR Glenohumeral OR Gleno-humeral OR Shoulder* OR "Upper extremity*" OR "Acromioclavicular Joint" OR "Rotator Cuff" OR "Shoulder joint" OR "Upper extremity" OR Clavicle	136,644
S6	"Randomi?ed control* trial*" OR RCTs OR RCT OR "Randomized controlled trial"	218,317
S7	S1 AND S2 AND S3 AND S4 AND S5 AND S6	477

iv) MEDLINE and PubMed Central (PMC) via PubMed

MEDLINE (Pubmed) search conducted on 03/08/2020 retrieving 689 results

Filter: Humans applied

Search	Query	Records retrieved
#1	"athlete*"[Text Word] OR "Competition"[Text Word] OR "contest*"[Text Word] OR "exercise*"[Text Word] OR "Game"[Text Word] OR "Handball"[Text Word] OR "javelin throw*"[Text Word] OR "Judo"[Text Word] OR "Karate"[Text Word] OR "kung fu"[Text Word] OR "overhead"[Text Word] OR "physical activit*"[Text Word] OR "physical exercise*"[Text Word] OR "pitcher*"[Text Word] OR "recreation*"[Text Word] OR "Softball"[Text Word] OR "Sport"[Text Word] OR "sport*"[Text Word] OR "tae kwon do"[Text Word] OR "taekwondo"[Text Word] OR "throw*"[Text Word] OR ("Track"[Text Word] AND "field"[Text Word]) OR "train*"[Text Word] OR "triathl*"[Text Word] OR "Workout"[Text Word] OR "wrestling*"[Text Word] OR "athletes"[MeSH Terms] OR "athletic performance"[MeSH Terms] OR "baseball"[MeSH Terms] OR "basketball"[MeSH Terms] OR "water sports"[MeSH Terms] OR "cricket	1,647,947

	sport"[MeSH Terms] OR "exercise"[MeSH Terms] OR "exercise movement techniques"[MeSH Terms] OR "track and field"[MeSH Terms] OR "football"[MeSH Terms] OR "games, recreational"[MeSH Terms] OR "golf"[MeSH Terms] OR "gymnastics"[MeSH Terms] OR "hockey"[MeSH Terms] OR "water sports"[MeSH Terms] OR "martial arts"[MeSH Terms] OR "motion"[MeSH Terms] OR "motor activity"[MeSH Terms] OR "movement"[MeSH Terms] OR "basketball"[MeSH Terms] OR "para athletes"[MeSH Terms] OR "exercise"[MeSH Terms] OR "physical exertion"[MeSH Terms] OR "physical fitness"[MeSH Terms] OR "water sports"[MeSH Terms] OR "racquet sports"[MeSH Terms] OR "recreation"[MeSH Terms] OR "water sports"[MeSH Terms] OR "soccer"[MeSH Terms] OR "sports"[MeSH Terms] OR "sports for persons with disabilities"[MeSH Terms] OR "sports medicine"[MeSH Terms] OR "swimming"[MeSH Terms] OR "tennis"[MeSH Terms] OR "volleyball"[MeSH Terms] OR "water sports"[MeSH Terms] OR "wrestling"[MeSH Terms] OR "youth sports"[MeSH Terms]	
#2	"balance exercise*"[Text Word] OR "calisthenic*"[Text Word] OR "exercise intervention*"[Text Word] OR "Flexibility"[Text Word] OR "intervenion*"[Text Word] OR "isometic*"[Text Word] OR "isotonic*"[Text Word] OR "neuromuscular program*"[Text Word] OR "neuromuscular training"[Text Word] OR "NMT"[Text Word] OR "range of motion"[Text Word] OR "strength training"[Text Word] OR "stretch*"[Text Word] OR "body weight"[MeSH Terms] OR "circuit based exercise"[MeSH Terms] OR "exercise therapy"[MeSH Terms] OR "muscle strength"[MeSH Terms] OR "muscle stretching exercises"[MeSH Terms] OR "proprioception"[MeSH Terms] OR "range of motion, articular"[MeSH Terms] OR "resistance training"[MeSH Terms] OR "yoga"[MeSH Terms]	803,533
#3	"decreas*"[Text Word] OR "incidence*"[Text Word] OR "injury rate*"[Text Word] OR "prehab*"[Text Word] OR "prevent*"[Text Word] OR "Prevention"[Text Word] OR ("Prevention"[Text Word] AND "control*"[Text Word]) OR "prevention program*"[Text Word] OR "prevention protocol*"[Text Word] OR "Prophylaxis"[Text Word] OR "reduc*"[Text Word] OR "risk*"[Text Word] OR ("accident prevention"[MeSH Terms] OR "incidence"[MeSH Terms] OR ("prevention and control"[MeSH Subheading] AND "prevention and control"[MeSH Subheading]) OR "primary prevention"[MeSH Terms] OR "program evaluation"[MeSH Terms] OR "risk assessment"[MeSH Terms] OR "risk management"[MeSH Terms]) OR "risk reduction behavior"[MeSH Terms]	8,954,296
#4	"accident"[Text Word] OR "dislocation*"[Text Word] OR "fracture*"[Text Word] OR "Glenohumeral"[Text Word] OR "Gleno-humeral"[Text Word] OR "injur*"[Text Word] OR "instab*"[Text Word] OR "joint instabilit*"[Text	6,737,673

	Word] OR "pain*"[Text Word] OR "problem*"[Text Word] OR (("range of motion, articular"[MeSH Terms] OR ("range"[All Fields] AND "motion"[All Fields] AND "articular"[All Fields]) OR "articular range of motion"[All Fields] OR ("range"[All Fields] AND "motion"[All Fields]) OR "range of motion"[All Fields]) AND "subluxation*"[Text Word]) OR "shoulder fracture*"[Text Word] OR "shoulder impingement syndrome*"[Text Word] OR "shoulder injur*"[Text Word] OR "shoulder pain*"[Text Word] OR "shoulder*"[Text Word] OR "strain*"[Text Word] OR "syndrom*"[Text Word] OR "trauma"[Text Word] OR "upper extremity*"[Text Word] OR ("accidents"[MeSH Terms] OR "acromioclavicular joint"[MeSH Terms] OR "athletic injuries"[MeSH Terms] OR "cumulative trauma disorders"[MeSH Terms] OR "fractures, bone"[MeSH Terms] OR "fractures, cartilage"[MeSH Terms] OR "joint instability"[MeSH Terms] OR "musculoskeletal system"[MeSH Terms] OR "pathology"[MeSH Terms] OR "rotator cuff"[MeSH Terms] OR "rotator cuff injuries"[MeSH Terms] OR "scapula"[MeSH Terms] OR "shoulder dislocation"[MeSH Terms] OR "shoulder fractures"[MeSH Terms] OR "shoulder impingement syndrome"[MeSH Terms] OR "shoulder injuries"[MeSH Terms] OR "shoulder joint"[MeSH Terms] OR "shoulder pain"[MeSH Terms] OR "shoulder injuries"[MeSH Terms] OR "soft tissue injuries"[MeSH Terms] OR "sprains and strains"[MeSH Terms] OR "tendon injuries"[MeSH Terms] OR "tendons"[MeSH Terms] OR "upper extremity"[MeSH Terms]) OR "wounds and injuries"[MeSH Terms]	
#5	"collar bone"[Text Word] OR "Glenohumeral"[Text Word] OR "Gleno-humeral"[Text Word] OR "shoulder*"[Text Word] OR "upper extremity*"[Text Word] OR "acromioclavicular joint"[MeSH Terms] OR "rotator cuff"[MeSH Terms] OR "shoulder joint"[MeSH Terms] OR "upper extremity"[MeSH Terms] OR "clavicle"[MeSH Terms]	252,143
#6	"Randomized controlled trial [Text word] OR "RCT"[Text Word] OR "RCTs"[Text Word] OR "randomized controlled trial"[Publication Type]	559,757
#7	"humans"[Filter]	18,735,137
#8	#1 AND #2 AND #3 AND #4 AND #5 AND #6 AND #7	689

v) Physiotherapy Evidence Database (PEDro)

Search conducted on Pedro on the 05/09/2020 retrieving 69 results

Filter: None (unable to filter for Humans)

Unable to perform complex boolean search

Search performed with advance search under following subheadings in the abstract and title:

Abstract & Title	Exercise* (Keyword used)
Body Part	Upper arm, Shoulder or Shoulder Girdle (drop down selection)
Subdiscipline	Sports (drop down selection)
Methods	Clinical trials (drop down selection)

vi) ProQuest Health & Medical Complete and Nursing & Allied Health Source (ProQuest complete)

Search conducted on the 06/09/2020 retrieving 197 results.

The following databases are affiliated with the platform allowing for a combined search:
1. ProQuest Health and Medical Complete
2. ProQuest Nursing and Allied Health Source

Search anywhere but full text (NOFT) and Medical Subject Headings (MeSH)
Limiters selected - None

noft(Athletic? OR Competition OR Contest* OR Exercise* OR Game OR Handball OR "javelin throw*" OR jijutsu OR ji-jutsu OR Judo OR Karate OR "Kung Fu" OR overhead OR "Physical activit*" OR "Physical exercise*" OR Pitcher* OR Recreation* OR Softball OR Sport? OR Sport* OR "Tae Kwon Do" OR taekwondo OR Throw* OR "Track and field" OR train* OR Triathl* OR Workout OR wrestling*) AND noft("balance exercise*" OR Calisthenic* OR "Exercise intervention*" OR Flexibility OR Intervenion* OR Isometic* OR Isotonic* OR "Neuromuscular program*" OR "Neuromuscular training" OR NMT OR "Range of motion" OR "Strength training" OR Stretch*) AND noft(Decreas* OR Incidence* OR "Injury rate*" OR Prehab* OR Prevent* OR Prevention OR "Prevention and control*" OR "Prevention program*" OR "Prevention protocol*" OR Prophylaxis OR Reduc* OR risk*) AND noft(accident? OR dislocation* OR fracture* OR injur* OR instab* OR "Joint Instabilit*" OR pain* OR problem* OR "range of motion subluxation*" OR "Shoulder Fracture*" OR "Shoulder Impingement Syndrome*" OR "Shoulder injur*" OR "Shoulder Pain*" OR strain* OR syndrom* OR trauma*) AND noft(Collar bone OR Glenohumeral OR Gleno-humeral OR Shoulder* OR "Upper limb*") AND noft(Randomi?ed control* trial*) AND MESH(Athletes OR "athletic performance" OR Baseball OR Basketball OR Canoeing OR "Cricket Sport" OR Exercise OR "Exercise movement techniques" OR "Field and Track" OR Football OR "Field and Track" OR "Games, Recreational" OR Golf OR Gymnastics OR Hockey OR Kayaking OR "Martial arts" OR Motion OR "Motor activity" OR Movement OR Netball OR "Para-Athletes" OR "Physical exercises" OR "Physical exertion" OR "Physical fitness" OR "Polo, Water" OR "Racquet Sports" OR Recreation OR Rowing OR Soccer OR "Sports for Persons with Disabilities" OR "Sports Medicine" OR Swimming OR Tennis OR Volleyball OR "Water Sports" OR Wrestling OR "Youth Sports") AND MESH("Body weight" OR "Circuit-Based Exercise" OR "Exercise therapy" OR "Muscle Strength" OR "Muscle Stretching Exercises" OR Proprioception OR "Range of Motion, Articular" OR "Resistance Training" OR Yoga) AND MESH("Accident prevention" OR "Health Risk Behaviors" OR

Incidence OR "Prevention and control" OR "Primary prevention" OR "Program evaluation" OR "Risk assessment" OR "Risk management" OR "Risk reduction behavior") AND MESH(Accidents OR "Athletic injuries" OR "Cumulative Trauma Disorders" OR "fractures, bone" OR "fractures, cartilage" OR "joint instability" OR "musculoskeletal system" OR pathology OR "Rotator Cuff Injuries" OR "Shoulder dislocation" OR "Shoulder Fractures" OR "Shoulder Impingement Syndrome" OR "Shoulder injuries" OR "Shoulder Pain" OR "SLAP Tear" OR "soft tissue injuries" OR "sprains and strains" OR "tendon injuries" OR Tendons OR "Wounds and Injuries") AND MESH("Acromioclavicular Joint" OR "Rotator Cuff " OR "Shoulder joint" OR "Upper extremity")

vii) ScienceDirect (Elsevier)

Search conducted on ScienceDirect (Elsevier) on the 05/09/2020 retrieving 877 results

Filter applied: Research Articles
Title, Abstract or author-specified keyword search: Exercise AND Shoulder OR "upper extremity" AND randomised controlled trials AND Sport OR Athlete AND Prevention AND Injury (Limited 8 Boolean connectors)

Athletes OR "athletic performance" OR Baseball OR Basketball OR Canoeing OR "Cricket Sport" OR Exercise OR "Exercise movement techniques" OR "Field and Track" OR Football OR "Field and Track" OR "Games, Recreational" OR Golf OR Gymnastics OR Hockey OR Kayaking OR "Martial arts" OR Motion OR "Motor activity" OR Movement OR Netball OR "Para-Athletes" OR "Physical exercises" OR "Physical exertion" OR "Physical fitness" OR "Polo, Water" OR "Racquet Sports" OR Recreation OR Rowing OR Soccer OR "Sports for Persons with Disabilities" OR "Sports Medicine" OR Swimming OR Tennis OR Volleyball OR "Water Sports" OR Wrestling OR "Youth Sports" AND "Body weight" OR "Circuit-Based Exercise" OR "Exercise therapy" OR "Muscle Strength" OR "Muscle Stretching Exercises" OR Proprioception OR "Range of Motion, Articular" OR "Resistance Training" OR Yoga AND "Accident prevention" OR "Health Risk Behaviors" OR Incidence OR "Prevention and control" OR "Primary prevention" OR "Program evaluation" OR "Risk assessment" OR "Risk management" OR "Risk reduction behavior" AND Accidents OR "Athletic injuries" OR "Cumulative Trauma Disorders" OR "fractures, bone" OR "fractures, cartilage" OR "joint instability" OR "musculoskeletal system" OR pathology OR "Rotator Cuff Injuries" OR "Shoulder dislocation" OR "Shoulder Fractures" OR "Shoulder Impingement Syndrome" OR "Shoulder injuries" OR "Shoulder Pain" OR "SLAP Tear" OR "soft tissue injuries" OR "sprains and strains" OR "tendon injuries" OR Tendons OR "Wounds and Injuries" AND "Acromioclavicular Joint" OR "Rotator Cuff " OR "Shoulder joint" OR "Upper extremity" OR Clavicle

viii) Scopus (Elsevier)

Search conducted on Scopus (Elsevier) on the 05/09/2020 retrieving 468 results

Filters applied: Human/s (Keyword), Randomized Controlled Trial (Keyword), Articles (Document type), Reviews (Document type), Medicine (Subject area), Health profession (Subject area)

Search word variations selected

Title, abstract and keywords searched

TITLE-ABS-KEY(Athletes OR "athletic performance" OR Baseball OR Basketball OR Canoeing OR "Cricket Sport" OR Exercise OR "Exercise movement techniques" OR "Field and Track" OR Football OR "Field and Track" OR "Games, Recreational" OR Golf OR Gymnastics OR Hockey OR Kayaking OR "Martial arts" OR Motion OR "Motor activity" OR Movement OR Netball OR "Para-Athletes" OR "Physical exercises" OR "Physical exertion" OR "Physical fitness" OR "Polo, Water" OR "Racquet Sports" OR Recreation OR Rowing OR Soccer OR "Sports for Persons with Disabilities" OR "Sports Medicine" OR Swimming OR Tennis OR Volleyball OR "Water Sports" OR Wrestling OR "Youth Sports" OR Athlete* OR Athletic? OR Competition OR Contest* OR Exercise* OR Game OR Handball OR "javelin throw*" OR jijutsu OR ji-jutsu OR Judo OR Karate OR "Kung Fu" OR overhead OR "Physical activit*" OR "Physical exercise*" OR Pitcher* OR Recreation* OR Softball OR Sport? OR Sport* OR "Tae Kwon Do" OR taekwondo OR Throw* OR "Track and field" OR train* OR Triathl* OR Workout OR wrestling* AND "Body weight" OR "Circuit-Based Exercise" OR "Exercise therapy" OR "Muscle Strength" OR "Muscle Stretching Exercises" OR Proprioception OR "Range of Motion, Articular" OR "Resistance Training" OR Yoga OR "balance exercise*" OR Calisthenic* OR "Exercise intervention*" OR Flexibility OR Intervenion* OR Isometic* OR Isotonic* OR "Neuromuscular program*" OR "Neuromuscular training" OR NMT OR "Range of motion" OR "Strength training" OR Stretch* AND "Accident prevention" OR "Health Risk Behaviors" OR Incidence OR "Prevention and control" OR "Primary prevention" OR "Program evaluation" OR "Risk assessment" OR "Risk management" OR "Risk reduction behavior" OR Decreas* OR Incidence* OR "Injury rate*" OR Prehab* OR Prevent* OR Prevention OR "Prevention and control*" OR "Prevention program*" OR "Prevention protocol*" OR Prophylaxis OR Reduc* OR risk* AND Accidents OR "Athletic injuries" OR "Cumulative Trauma Disorders" OR "fractures, bone" OR "fractures, cartilage" OR "joint instability" OR "musculoskeletal system" OR pathology OR "Rotator Cuff Injuries" OR "Shoulder dislocation" OR "Shoulder Fractures" OR "Shoulder Impingement Syndrome" OR "Shoulder injuries" OR "Shoulder Pain" OR "SLAP Tear" OR "soft tissue injuries" OR "sprains and strains" OR "tendon injuries" OR Tendons OR "Wounds and Injuries" OR accident? OR dislocation* OR fracture* OR injur* OR instab* OR "Joint Instabilit*" OR pain* OR problem* OR "range of motion subluxation*" OR "Shoulder Fracture*" OR "Shoulder Impingement Syndrome*" OR "Shoulder injur*" OR "Shoulder Pain*" OR strain* OR syndrom* OR trauma* AND "Acromioclavicular Joint" OR "Rotator Cuff " OR "Shoulder joint" OR "Upper extremity" OR Clavicle OR Collar bone OR Glenohumeral OR Gleno-humeral OR Shoulder* OR "Upper extremity*" AND Randomized controlled trial OR Randomi?ed control* trial*) AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"re")) AND (LIMIT-TO (SUBJAREA,"MEDI") OR LIMIT-TO (SUBJAREA,"HEAL")) AND (LIMIT-TO (EXACTKEYWORD,"Human") OR LIMIT-TO (EXACTKEYWORD,"Humans") OR LIMIT-TO (EXACTKEYWORD,"Randomized Controlled Trial"))

ix) Web of Sciences (Clarivate Analytics)

Search conducted on the 05/09/2020 retrieving 314 results.

Filters applied: Human/s (Keyword), Randomized Controlled Trial (Keyword), Articles (Document type), Reviews (Document type), Medicine (Subject area), Health profession (Subject area)
Search word variations selected
Title, abstract and keywords searched

TITLE-ABS-KEY(Athletes OR "athletic performance" OR Baseball OR Basketball OR Canoeing OR "Cricket Sport" OR Exercise OR "Exercise movement techniques" OR "Field and Track" OR Football OR "Field and Track" OR "Games, Recreational" OR Golf OR Gymnastics OR Hockey OR Kayaking OR "Martial arts" OR Motion OR "Motor activity" OR Movement OR Netball OR "Para-Athletes" OR "Physical exercises" OR "Physical exertion" OR "Physical fitness" OR "Polo, Water" OR "Racquet Sports" OR Recreation OR Rowing OR Soccer OR "Sports for Persons with Disabilities" OR "Sports Medicine" OR Swimming OR Tennis OR Volleyball OR "Water Sports" OR Wrestling OR "Youth Sports" OR Athlete* OR Athletic? OR Competition OR Contest* OR Exercise* OR Game OR Handball OR "javelin throw*" OR jijutsu OR ji-jutsu OR Judo OR Karate OR "Kung Fu" OR overhead OR "Physical activit*" OR "Physical exercise*" OR Pitcher* OR Recreation* OR Softball OR Sport? OR Sport* OR "Tae Kwon Do" OR taekwondo OR Throw* OR "Track and field" OR train* OR Triathl* OR Workout OR wrestling* AND "Body weight" OR "Circuit-Based Exercise" OR "Exercise therapy" OR "Muscle Strength" OR "Muscle Stretching Exercises" OR Proprioception OR "Range of Motion, Articular" OR "Resistance Training" OR Yoga OR "balance exercise*" OR Calisthenic* OR "Exercise intervention*" OR Flexibility OR Intervenion* OR Isometic* OR Isotonic* OR "Neuromuscular program*" OR "Neuromuscular training" OR NMT OR "Range of motion" OR "Strength training" OR Stretch* AND "Accident prevention" OR "Health Risk Behaviors" OR Incidence OR "Prevention and control" OR "Primary prevention" OR "Program evaluation" OR "Risk assessment" OR "Risk management" OR "Risk reduction behavior" OR Decreas* OR Incidence* OR "Injury rate*" OR Prehab* OR Prevent* OR Prevention OR "Prevention and control*" OR "Prevention program*" OR "Prevention protocol*" OR Prophylaxis OR Reduc* OR risk* AND Accidents OR "Athletic injuries" OR "Cumulative Trauma Disorders" OR "fractures, bone" OR "fractures, cartilage" OR "joint instability" OR "musculoskeletal system" OR pathology OR "Rotator Cuff Injuries" OR "Shoulder dislocation" OR "Shoulder Fractures" OR "Shoulder Impingement Syndrome" OR "Shoulder injuries" OR "Shoulder Pain" OR "SLAP Tear" OR "soft tissue injuries" OR "sprains and strains" OR "tendon injuries" OR Tendons OR "Wounds and Injuries" OR accident? OR dislocation* OR fracture* OR injur* OR instab* OR "Joint Instabilit*" OR pain* OR problem* OR "range of motion subluxation*" OR "Shoulder Fracture*" OR "Shoulder Impingement Syndrome*" OR "Shoulder injur*" OR "Shoulder Pain*" OR strain* OR syndrom* OR trauma* AND "Acromioclavicular Joint" OR "Rotator Cuff " OR "Shoulder joint" OR "Upper extremity" OR Clavicle OR Collar bone OR Glenohumeral OR Gleno-humeral OR Shoulder* OR "Upper extremity*" AND Randomized controlled trial OR Randomi?ed control* trial*) AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"re")) AND (LIMIT-TO (SUBJAREA,"MEDI") OR LIMIT-TO (

SUBJAREA,"HEAL")) AND (LIMIT-TO (EXACTKEYWORD,"Human") OR LIMIT-TO (EXACTKEYWORD,"Humans") OR LIMIT-TO (EXACTKEYWORD,"Randomized Controlled Trial"))

Appendix B: JBI Critical Appraisal Checklist for Randomized Controlled Trials

JBI Critical Appraisal Checklist for Randomized Controlled Trials

Reviewer______________________________________`____________Date______________________

Author ____________________________Year_____________Record Number_______

	Yes	No	Unclear	NA
1. Was true randomization used for assignment of participants to treatment groups?	□	□	□	□
2. Was allocation to treatment groups concealed?	□	□	□	□
3. Were treatment groups similar at the baseline?	□	□	□	□
4. Were participants blind to treatment assignment?	□	□	□	□
5. Were those delivering treatment blind to treatment assignment?	□	□	□	□
6. Were outcomes assessors blind to treatment assignment?	□	□	□	□
7. Were treatment groups treated identically other than the intervention of interest?	□	□	□	□
8. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	□	□	□	□
9. Were participants analyzed in the groups to which they were randomized?	□	□	□	□
10. Were outcomes measured in the same way for treatment groups?	□	□	□	□
11. Were outcomes measured in a reliable way?	□	□	□	□
12. Was appropriate statistical analysis used?	□	□	□	□
13. Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	□	□	□	□

Overall appraisal: Include □ Exclude □ Seek further info □

Comments (Including reason for exclusion)

____

____

Appendix C: Data extraction instrument

The JBI Data extraction instrument will be modified to include the following data points: First Author's last name; Publication year; Critical appraisal rating; Country; Setting (sport, level); Participants (sex, age); Sample (sample size, declined to participate, drop-out rate, the sample analysed, intention-to-treat or per-protocol analysis, cluster adjustment); Intervention (name or description, intervention type, frequency, dose, compliance, categorisation, open *versus* closed kinetic chain shoulder exercises); Outcome measures (shoulder or upper extremity, number of injuries in the intervention *versus* the control group, acute *versus* overuse injuries, primary outcome); Bias and main limitations.

First Author's last name	
Publication year	
Appraisal rating	
Country	
Setting - Sport - Level	
Participants - Sex - Age	
Sample - Sample size - Declined to participate - Drop-out rate - Sample analysed - ITT/PP analysis - Cluster adjusted	
Intervention - Name or description - Type - Frequency - Dose - Compliance - Categorisation - OKC vs CKC	
Outcome measures - shoulder or upper extremity - number of injuries (INV vs CON) - acute *versus* overuse - Primary outcome	
Bias and main limitations	

Appendix D: Table of excluded articles

Author/Study	Reason for exclusion
Al Attar and Alshehri (2019a)	The article has only an abstract available as it is unpublished. Contact with the author revealed that the publication date is 2021 and that no data may currently be shared.
Baadjou et al. (2014)	The target population was music students and did not qualify as a target population. The inclusion criteria were not met.
Fer et al. (2017)	The abstract was translated from French into English using Google Translate. The study provided no injury incidence or data for the shoulder or upper extremity and provided only lower extremity data.
Forrest et al. (2020)	They provided surrogate measures of injury reduction. The study tested the ability to potentially reduce the risk of injury and did not gather injury incidence data.
Fredriksen et al. (2020)	The study has no specific incidence on the shoulder or upper extremity. The corresponding author has responded on the request for more information on the incidence of shoulder injuries or raw data but is unable to supply.
Gouttebarge et al. (2020)	The study has no specific incidence on the shoulder or upper extremity. The corresponding author responded that he does not have access to the raw data and that the study did not analyse any data regarding specific body regions.
Kissenberth et al. (2016)	Identical study as Thigpen et al. (2016). Two abstracts under two different authors. Contact with the other author was successful.
Reinold et al. (2018)	The study has no specific data on the incidence on the shoulder and focussed on surrogate measures of injury.
Sakata et al. (2018)	The study is a cohort study and not a randomised controlled trial. The inclusion criteria were not met.
Shanley et al. (2014)	The article has only an abstract available. The corresponding author has not responded on the request for raw data and full text.
Thigpen et al. (2016)	The article has only an abstract available as it is unpublished. Contact with the author revealed that the complete paper has not been published by the AJSM and is embargoed until 2021.

Appendix E: Extraction tables

Study	Al Attar *et al.*	Andersson *et al.*	Attwood *et al.*
Publication year	2017	2016	2017
Appraisal rating	92.30%	61.54%	53.84%
Country	Australia	Norway	England
Setting ▪ Sport	Football	Handball	Rugby
Setting ▪ Level	Two club levels (Amateur Premier Leagues and State League) Amateur: n = EXP 7 (70%), n = CON 10 (91%)	Elite level teams	Rugby Football Union Levels 3-9 ▪ EXP: (Semi-professional = 2) (Amateur = 10) (Recreational = 29) ▪ CON: (Semi-professional = 2) (Amateur = 9) (Recreational = 29)
Population ▪ Sex ▪ Age – Mean (SD)	Males 14 – 35 yrs. ▪ EXP 18 (6) yrs. ▪ CON 16 (4) yrs.	Females & Males 18 – 28 yrs. ▪ EXP: F = 22.5 (4.2) M = 21.9 (3.7) yrs. ▪ CON: F = 21.6 (3.3) M = 23.5 (4.8) yrs.	Males Mean all players: 25.5 (5.6) yrs. ▪ EXP: 26.1 (5.7) yrs. ▪ CON: 25.0 (5.5) yrs.
Sample ▪ Sample size	21 teams, n = 344 ▪ EXP: 10 teams, n = 160 ▪ CON: 11 teams, n = 184	46 teams, n = 677 ▪ EXP: 22 teams, n = 331 ▪ CON: 23 teams, n = 329	81 clubs, n = 673 ▪ EXP: 41 clubs, n = 273 ▪ CON: 40 clubs, n = 400
Sample ▪ Declined (%) ▪ Drop-out rate (%)	Declined participation: 24 teams (53.33%) Dropped out during study: ▪ EXP: 1 team, n = 16 (4.65%) ▪ CON: 3 teams, n = 38 (11.05%)	Declined participation: n = 45 (6.38%) Dropped out during study: ▪ EXP: n = 51 (15.41%) ▪ CON: n = 39 (11.85%)	Declined participation: 45 clubs (90.53%) Dropped out during study: ▪ EXP = 19 clubs (46.34%) ▪ CON = 21 clubs (52.50%)
Sample ▪ Analysed (%)	▪ EXP: 10 teams, n = 160 (100%) ▪ CON: 11 teams, n = 184 (100%)	▪ EXP: n = 264 (79.76%) ▪ CON n = 270 (82.01%)	▪ EXP: 22 teams, n = 122 (53.66%) ▪ CON 19 teams, n = 133 (47.50%)
Sample ▪ ITT/PP analysis	ITT (True model)	Not mentioned – PP used	Modified-ITT & PP used
Sample ▪ Cluster adjusted	Cluster adjusted (GEE binominal regression)	Cluster adjusted (ICC < 0.1)	Cluster adjusted (cluster coefficient k = 0.26)
Intervention ▪ Name or description ▪ Type	FIFA 11+ programme ▪ EXP: Warm-up and warm-down ▪ CON: Regular warm-up	OSTRC Shoulder IPP ▪ EXP: Warm-up ▪ CON: Regular warm-up	▪ EXP: IPP warm-up designed by a technical group for Rugby ▪ CON: Control programme
Intervention ▪ Frequency (total number)	2 - 3 x per week for six months (52 – 78)	3 x per week for six months (78)	2 x per week at training and 1 x per week pre-match for 42 weeks (126)
Intervention	EXP: FIFA 11+ pre-training 20 min & post-training 10 minutes (39 *h*)	10 min pre-training or throwing (13 *h*)	5 – 10 min of small-sided games and then 15 min of main exercise content (42 – 52.5 *h*)

▪ **Dose (total hours)**	CON: FIFA 11+ pre-training 20 min (26 *h*)					
Intervention ▪ **Compliance (%)**	EXP: 9 teams 65 / 78 sessions (83%) CON: 8 teams 60 / 78 sessions (77%)		Average of 1.6 times per week (1.4-1.8) [53%]		EXP: Average of 2.1 ± 0.7 per week (85%) CON: Average of 2.2 ± 0.6 per week, (83%)	
Intervention ▪ **Categorisation** ▪ **OKC vs CKC**	Not explicitly targeting the upper extremity Total: n = 27 (30 min) Upper extremity: n = 9 Mainly planking on arms for CKC		Specifically designed to target the shoulder Total: n = 5 (10 min) Upper extremity: n = 4 Three levels of each exercise progressed every six weeks		Limited targeting of the shoulder Total: n = 16 (25 min), only provided a sample of phase III of the program progressions. Upper extremity: n = 4	
	Strength:	0	Strength:	1 (24 - 48 reps)	Strength:	4 (30 reps & 60 sec)
	Flexibility:	0	Flexibility:	1 (90 sec)	Flexibility:	0
	Mobility:	0	Mobility:	1 (24 - 48 reps)	Mobility:	0
	Proprioception:	4 (450 sec)	Proprioception:	0	Proprioception:	0
	Plyometrics:	1 (120 sec)	Plyometrics:	1 (30 - 60 reps)	Plyometrics:	0
	Functional:	3 (300 sec)	Functional:	0	Functional:	0
	Multimodal:	1 (120 sec)	Multimodal:	1 (24 - 48 reps)	Multimodal:	0
	OKC vs CKC	OKC 2 (240 sec) *vs* CKC 7 (750 sec)	OKC vs CKC	OKC 4 (75 - 147 reps) *vs* CKC 1 (24 - 48 reps)	OKC vs CKC	OKC 2 (60 sec) *vs* CKC 2 (30 reps)
Outcome measure ▪ **Shoulder or upper extremity**	Specified shoulders + arms + elbows + forearms + wrists = Upper extremity		Specified shoulder data for the dominant arm only		Specified Shoulder + shoulder girdle + elbows + forearms + hand = Upper extremity	
Outcome measure ▪ **Number of injuries (EXP vs CON)**	Shoulder injuries ▪ EXP 1, CON 2 Arm injuries: ▪ EXP 1, CON 1 Elbow injuries: ▪ EXP 1, CON 1 Forearm injuries: ▪ EXP 0, CON 1 Wrist injuries: ▪ EXP 1, CON 2 Upper extremity injuries: ▪ EXP 4*, CON 7*		Acute shoulder injuries: ▪ EXP 20, CON 13 Overuse shoulder problems: ▪ EXP 73, CON 83 Upper extremity injuries & problems: ▪ EXP 93*, CON 96*		Shoulder injuries: ▪ EXP 17, CON 10 Shoulder girdle injuries: ▪ EXP 11, CON 5 Elbow injuries: ▪ EXP 1, CON 3, Forearm & hand injuries: ▪ EXP 8, CON 6	
Outcome measure ▪ **Acute vs overuse**	Overuse injuries not investigated		Prevalence of acute shoulder injuries: ▪ EXP: 1.4% (95% CI 0.8% - 1.9%) ▪ CON: 0.9% (95% CI 0.5% - 1.2%) Prevalence of overuse shoulder problems: ▪ EXP: 17% (95% CI 16% - 19%) ▪ CON: 23% (95% CI 21% - 26%)		Overuse injuries not investigated	

Outcome measure ▪ **Primary outcome**	Positive IRR was 0.28 & statistically significant with adequate power (95% CI 0.18 to 0.44), indicating a 72% reduction in injuries in the EXP group vs CON group	Positive 28% reduced risk (OR 0.72, 95% CI 0.52 to 0.98, p = 0.038) & 22% reduced risk of substantial problems (OR 0.78, 95% CI 0.53 to 1.16, p = 0.23) was found in favour of the EXP	ITT = Inconclusive for overall injury burden, incidence, or severity. Positive for lower extremity incidence reduced by 40% (RR, 90% CI=0.6, 0.4 - 1.0) and concussion incidence by 60% (RR, 90% CI=0.4, 0.2 - 0.7). PP = Negative result for shoulder **possibly harmful** (RR: 1.5, 90% CI 0.6 – 3.7)
Bias and main limitations	1. Investigator visited EXP vs CON at 2:1 ratio 2. EXP monitored more frequently to ensure compliance 3. The analysis did not factor in engagement in other sports 4. Reason for drop-out: Limited training time not explained	1. More follow-up visits to EXP 2. Data gathered only for the dominant shoulder 3. Lack of detailed diagnostic information 4. CON reported doing more strength training 5. Low compliance of 53% 6. Recall bias: Self-reported measures asked players to recall data from the past seven days	1. Random checks of club compliance through unannounced visits were not made 2. High decline to participate and drop-out rate 3. The analysis did not factor in engagement in other sports

Study	**Finch *et al.***	**Hislop *et al.***	**Olsen *et al.***
Publication year	2016	2017	2005
Appraisal rating	76.92%	69.23%	69.23%
Country	Australia	UK	Norway
Setting ▪ **Sport**	Australian Football	Rugby	Handball
Setting ▪ **Level**	Adult Community level (Non-Elite) Seniors: EXP 27, CON: 33 Reserves/Colts: EXP: 11, CON: 26	School: Under-15, Under-16 and Under-18 Youth	Norwegian handball federation league Youth
Population ▪ **Sex** ▪ **Age – Mean (SD)**	Males No baseline demographics for age and level as only a subset was sampled	Males 14- 18 yrs. ▪ EXP: 16.0 yrs. ▪ CON: 15.9 yrs.	Females & Males 15 -17 yrs. ▪ EXP: 16.3 (0.6) yrs. ▪ CON: 16.2 (0.6) yrs.
Sample ▪ **Sample size**	n = 1691 ▪ EXP: n = 751 ▪ CON: n = 940	40 schools, 118 teams, n = 3188 ▪ EXP: 20 schools, 60 teams, n = 1645 ▪ CON: 20 schools, 58 teams, n = 1543	123 clubs, n = 1886 ▪ EXP: 62 clubs, n = 988 ▪ CON: 61 clubs, n = 898
Sample ▪ **Declined (%)** ▪ **Drop-out rate (%)**	Declined participation: Unknown Excluded from participation: n = 326 (16.16%) Excluded: ▪ EXP: n = 72 (9.59%) ▪ CON: n = 55 (5.85%)	Declined participation: 168 Schools (76.36%) Dropped out during study: ▪ EXP: n = 320 (19.45%) ▪ CON: n = 416 (26.96%)	Declined participation: 22 clubs (15.17%) Excluded after randomization: ▪ EXP: 1 club, n = 30 (3.03%) ▪ CON: 2 clubs, n = 19 (2.12%) Dropped out during study: ▪ EXP: n = 68 (7.10%) ▪ CON: n = 51 (5.80%)

Sample ▪ **Analysed (%)**	▪ EXP: 38 teams, n = 679 (90.41%) ▪ CON: 59 teams, n = 885 (94.15%)		▪ EXP: 17 schools, 44 teams, n = 1325 (80.55%) ▪ CON: 14 schools, 39 teams, n = 1127 (70.04%)		▪ EXP: 61 clubs, n = 958 (96.96%) ▪ CON: 59 clubs, n = 879 (97.88%)	
Sample ▪ **ITT/PP analysis**	Modified-ITT		Modified-ITT & PP		ITT (True model)	
Sample ▪ **Cluster adjusted**	Cluster adjusted (ICC = 0.0117)		Not Mentioned		Cluster adjusted (ICC 0.043 – 0.071) inflation factor 2	
Intervention ▪ **Name or description** ▪ **Type**	▪ EXP: Neuromuscular control programme (warm-up) ▪ CON: Sham exercise programme		Phase based progressive program ▪ EXP: Movement control exercise programme (warm-up) ▪ CON: Running-based warm-up		▪ EXP: Structured warm-up programme with a focus on knees and ankle ▪ CON: Training as usual	
Intervention ▪ **Frequency (total number)**	2 x per week for 26 weeks (54)		Five months no prescribed frequency		Start of training for 15 consecutive sessions Then 1 x a week during the remainder of the season for 8 Months (55)	
Intervention ▪ **Dose (total hours)**	No longer than the first 20 minutes of a training session (18 *h*)		Done during the first 20 minutes of a pitch-based training session and match warm-up		4 - 5 min for each exercise group Total of 15 - 20 minutes (13,75 – 18.33*h*)	
Intervention ▪ **Compliance (%)**	Compliancy was not measured; many players did not train regularly and most did not attend the two weekly sessions		▪ EXP: 1.9 sessions/week (69%) ▪ CON: 2.0 sessions/week (83%)		▪ EXP: Compliance (87%) among youth clubs ▪ CON: 13 clubs **(22%) used specific IPPs**	
Intervention ▪ **Categorisation** ▪ **OKC vs CKC**	Not explicitly targeting the upper extremity ▪ EXP: Incidental upper extremity work Total: n = 27 (20 min) Upper extremity: n = 2 (mostly catching ball)		Not explicitly targeting the upper extremity Total: n = 12 (20 min), provided a sample of phase II of the program progressions for U15. Upper extremity: n = 4		Not explicitly targeting the upper extremity Total: n = 17 Upper extremity: n = 4 Mainly passing while balancing	
	Strength:	0	Strength:	0	Strength:	1 (180 sec)
	Flexibility:	0	Flexibility:	0	Flexibility:	0
	Mobility:	0	Mobility:	0	Mobility:	0
	Proprioception:	0	Proprioception:	1 (30 sec)	Proprioception:	0
	Plyometrics:	2	Plyometrics:	1 (6 reps)	Plyometrics:	0
	Functional:	0	Functional:	2 (70 sec)	Functional:	0
	Multimodal:	0	Multimodal:	0	Multimodal:	3 (540 sec)
	OKC vs CKC	OKC 2 vs CKC 0	OKC vs CKC	OKC 0 vs CKC 4 (100 sec & 6 reps)	OKC vs CKC	OKC 4 (720 sec) vs CKC 0
Outcome measure ▪ **Shoulder or upper extremity**	Upper extremity		Shoulder & upper extremity		Specified shoulder & upper extremity	
Outcome measure	Upper extremity proportion: ▪ EXP: 14.0%, CON: 20.1%		Upper extremity IRR: ▪ EXP: 7, CON: 9		Acute shoulder injuries: ▪ EXP: 4, CON: 11	

▪ **Number of injuries (EXP vs CON)**	Upper extremity injuries: ▪ EXP 46.9*, CON 88.04*	Acute shoulder injuries:** ▪ EXP: 26, CON: 34	Upper extremity injuries: ▪ EXP: 17, CON: 39
Outcome measure ▪ **Acute vs overuse**	Overuse injuries not investigated	Overuse injuries not investigated	No specified overuse data All acute injuries: EXP 85 vs CON 156 All overuse injuries: EXP 18 vs CON 39
Outcome measure ▪ **Primary outcome**	Positive, but not statistically significant Reducing the knee injury rate by 50% with IRR 0.5 (95% CI 0.24 to 1.05, p = 0.07) and the lower extremity injury rate by 22% wit IRR 0.78 (95% CI 0.56 to 1.08, p = 0.14)	ITT = Inconclusive for overall match injuries & contact-related injuries RR = 0.85 (90% CI 0.61 to 1.17), but positive for head/neck injuries, **upper extremity injuries** and concussion PP = Positive result for EXP completing three or more session had 72% fewer overall match injuries RR = 0.28 (90% CI 0.14 to 0.51)	Positive Reduced knee & ankle injuries. Relative risk (95% CI) all injuries: 0.49 (0.36 to 0.68) Relative risk (95%CI) upper extremity injuries**:** **0.37 (0.20 to 0.69)**
Bias and main limitations	1. Low compliance 2. Frequency of exposure to the training programme could be quantified, but the fidelity was not formally measured 3. No baseline demographics for age and level as only a subset was sampled	1. Research team running pre-trial workshops & visits were not blinded 2. Individual player compliance not monitored during the study and compared to team compliance 3. Unable to validate coach compliance reports or exercise fidelity	1. Mentioned players withdrawing from the Norwegian Handball Federation league (no players played for these clubs) 2. 22% of the control group used specific exercises to prevent injury
Study	**Osteras et al.**	**Pas *et al.***	**Rössler *et al.***
Publication year	2015	2020	2017
Appraisal rating	15.39%	61.54%	69.23%
Country	Norway	Netherlands	Switzerland, Germany, Czech Republic, & Netherlands
Setting ▪ **Sport**	Handball	Tennis	Football
Setting ▪ **Level**	Junior league teams (Highest club level) Mean yrs. played: EXP 8.0 CON 8.1	Playing level singles range 1 – 10 ▪ EXP 7 (5 - 8), CON 7 (6 - 8) [All levels] Playing level doubles range 1 – 10 ▪ EXP 6 (5 - 8), CON 6 (5 - 7) [All levels]	Officially registered children football
Population ▪ **Sex** ▪ **Age – Mean (SD)**	Females 16 yrs. ▪ EXP & CON: 15,3 yrs.	Females & Males Adults (18 and older): ▪ EXP:41 (12) yrs. ▪ CON: 42 (13) yrs.	Females & Males 7 - 13 yrs. ▪ EXP & CON: 10.8 (1.4) yrs.
Sample ▪ **Sample size**	7 teams, n = 109 ▪ EXP: 3 teams, n = 53 ▪ CON: 4 teams, n = 56	n = 700 ▪ EXP: n = 349 ▪ CON: n = 351	176 Clubs, 273 teams, n = 4360 ▪ EXP: 139 teams, n = 2235 ▪ CON: 134 teams, n = 2125

Sample ▪ **Declined (%)** ▪ **Drop-out rate (%)**	Declined participation: Unknown Dropped out during study: ▪ EXP: n = 15 (28.30%) ▪ CON: n = 22 (39.29%)	Declined participation: Unknown Excluded: n = 384 (35.43%) Dropped out during study: ▪ EXP: n = 68 (19.48%) ▪ CON: n = 60 (17.09%)	Declined participation: 918 clubs (83.91%) Dropped out during study: ▪ EXP: 11 teams, n = 169 (7.56%) ▪ CON: 19 teams, n = 296 (13.93%)
Sample ▪ **Analysed (%)**	▪ EXP: n = 38** (72%) ▪ CON n = 34** (73%)	N = 579 included in analysis (83%) ▪ EXP: 286, CON: 293 Complete data available: n = 152 (21.71%) ▪ EXP: 60, CON:92	▪ EXP: 128 teams, n = 2066 (92.44%) ▪ CON: 115 teams, n = 1829 (86.07%)
Sample ▪ **ITT/PP analysis**	PP	Modified-ITT	Modified-ITT
Sample ▪ **Cluster adjusted**	Not cluster RCT (N/A)	Not cluster RCT (N/A)	Cluster adjusted (ICC 0.05) inflation factor 2.95
Intervention ▪ **Name or description** ▪ **Type**	▪ EXP: Three strength exercises warm-up program ▪ CON: Regular handball training program	▪ EXP: TennisReady Prevention program via app either on-court warm-up or **supplementary strength training** ▪ CON: Warming up & training as usual	▪ EXP: 11+ Kids injury prevention programme in place of warm-up. ▪ CON: Warm-up as usual
Intervention ▪ **Frequency (total number)**	3 x a week for six months. (78)	2 x a week for 12 weeks (24)	At least 2 x a week for one football season (from August/September 2014 to June/July 2015). [95]
Intervention ▪ **Dose (total hours)**	- 3 x 12 Push-up plus - 3 x 20 IR at 90 TheraBand - 3 x 20 ER at 90 TheraBand	7-10 minutes (2.8*h* – 4*h*)	15 – 20 Min (23.75*h* – 31.66*h*)
Intervention ▪ **Compliance (%)**	▪ EXP: completed 71% of prescribed shoulder strength training.	Response rate decreased over 16 weeks from EXP: 98% - 34%, CON: 97% - 48% ▪ EXP: 17% (total), CON: 26% (total)	Mean sessions per week: Low: 0.3 - 0.8, Medium 0.8 - 1.1, High 1.1 - 2.9
Intervention ▪ **Categorisation** ▪ **OKC vs CKC**	Exclusively targeting upper extremity ▪ Total: n = 3 exercises (156 reps)	Specifically targeting upper extremity (sample taken at 12 weeks) Alternating with on-court and off-court Total: n = S1 (10), S2 (8), S3 (5) & S4 (5) Upper extremity: n = S1 (5), S2 (4), S3 (3) & S4 (3) ▪ On-court with band & without (S1 & S2) ▪ Off-court with band & without (S3 & S4)	Whole-body neuromuscular integration Total: n = 7 Upper extremity: n = 5 Mainly integrated motor control movements
	Strength: 3 (156 reps)	Strength: 1 (S2) 1 (S3) 1 (S4) – per session 1	Strength: 2 (70 sec)
	Flexibility: 0	Flexibility: 0	Flexibility: 0
	Mobility: 0	Mobility: 3 (S1) 1 (S2) – per session 1	Mobility: 0
	Proprioception: 0	Proprioception: 0	Proprioception: 0

	Plyometrics:	0	Plyometrics:	0	Plyometrics:	0
	Functional:	0	Functional:	1 (S1) 1 (S2) 1 (S3) 2 (S4) – per session 1	Functional:	2 (21 reps)
	Multimodal:	0	Multimodal:	1 (S1) 1 (S2) 1 (S3) 1 (S4) – per session 1	Multimodal:	1 (40 sec)
	OKC vs CKC	OKC 2 (120reps) vs CKC 1 (36reps)	OKC vs CKC	OCK 13 *vs* CKC 3 per session - OCK 3 *vs* CKC 1	OKC vs CKC	OKC 3 (40 sec & 21 reps) vs CKC 2 (70 sec)
Outcome measure ▪ **Shoulder or upper extremity**	Specified shoulder		Specified shoulder + elbow = Upper extremity		Shoulder/Clavicle + Finger/hand/wrist/arm = Upper extremity	
Outcome measure ▪ **Number of injuries (EXP vs CON)**	Overuse shoulder complaints: ▪ EXP: 11% (4.18* number of injuries) ▪ CON: 36% (12.24* number of injuries) Shoulder complaints incidence: ▪ EXP 1, (0.028); CON 2, (0.063)		Shoulder injury incidence: ▪ EXP: 2.3 (1.5–3.4), CON: 2.5 (1.7–3.6) Shoulder injuries: EXP: 11.44*, CON: 14.65* Elbow injury incidence: ▪ EXP: 1.4 (0.9–2.4), CON: 2.0 (1.4–3.1) Upper extremity injuries: ▪ EXP: 20.02*, CON: 23.44*		Number of Shoulder/clavicle injuries: ▪ EXP: 2, CON: 4 Number of Finger/hand/wrist/arm injuries: ▪ EXP: 24, CON: 28 Upper extremity injuries: ▪ EXP: 26*, CON: 32*	
Outcome measure ▪ **Acute vs overuse**	55% of injured players reported that symptoms had a gradual onset.		Overuse injuries not investigated		Overuse injuries not investigated	
Outcome measure ▪ **Primary outcome**	Positive The shoulder-strengthening program reduced the shoulder complaints during a season of team handball		Inconclusive Overall injury prevalence over a 16-week programme with EXP 37% (95% CI 33% to 42%) vs CON 38% (95% CI 34% to 42%)		Positive Overall injury rate in EXP was reduced by 48% compared with CON (HR 0.45, 95% CI 0.32 – 0.86)	
Bias and main limitations	1. No reasons provided for drop-out 2. 15 CON players reported additional shoulder-strengthening training 3. Small sample size 4. The use of a retrospective questionnaire		1. Blinding and allocation concealment of the participants was not possible 2. Unable to verify completion exercise fidelity 3. No random visits or monitoring 4. Poor response rate of biweekly questionnaires, resulting in extensive missing data		1. Blinding of participants regarding group allocation was not possible 2. Medical diagnoses were not made 3. The drop-out rate was higher in CON (13.9%) than in EXP (7.6%) 4. Potential recall bias	

Study	**Sakata *et al.***	**Silvers-Granelli *et al.***	**Sommervold *et al.***
Publication year	2019	2015	2017
Appraisal rating	69.23%	46.15%	46.15%
Country	Japan	USA	Norway
Setting ▪ **Sport**	Baseball	Football	Handball

Setting ▪ **Level**	Youth Baseball Regional League	US National Collegiate Athletic Association ▪ Division I: EXP: n = 400, CON: n = 425 ▪ Division II: EXP: n = 275, CON: n = 425	Junior teams
Population ▪ **Sex** ▪ **Age – Mean (SD)**	Females & Males 9 – 11 yrs. ▪ EXP: 10.3 (0.8) yrs. ▪ CON: 10.2 (0.7) yrs.	Males 18 – 21 yrs. ▪ EXP: 20.68 (1.66) yrs. ▪ CON: 20.40 (1.46) yrs.	Females 16 yrs.
Sample ▪ **Sample size**	16 teams, n = 237 ▪ EXP: 8 teams, n = 117 ▪ CON: 8 teams, n = 120	65 teams, n = 1625 ▪ EXP: 31 teams, n = 775 ▪ CON: 34 teams, n = 850	6 teams, n = 106 ▪ EXP: 3 teams, n = 53 ▪ CON: 3 teams, n = 53
Sample ▪ **Declined (%)** ▪ **Drop-out rate (%)**	Declined participation: n = 21 (8.14%) Dropped out during study: ▪ EXP: 8 players (6.84%) ▪ CON: 10 players (8.33%)	Declined participation: 331 teams (83.59%) Dropped out during study: ▪ EXP: n = 100 (12.90%) ▪ CON: n = 0 (0%)	Declined participation: Unknown Dropped out during study: ▪ EXP: n = 7 (13.20%) ▪ CON: n = 12 (22.60%)
Sample ▪ **Analysed (%)**	▪ EXP: n = 109 (93.16%) ▪ CON: n = 110 (91.67%)	▪ EXP: 27 teams, n = 675 (87.10%) ▪ CON: 34 teams, n = 850 (100.00%)	▪ EXP: n = 46 (86.80%) ▪ CON: n = 41 (77.40%)
Sample ▪ **ITT/PP analysis**	Modified-ITT	Not mentioned - PP	PP
Sample ▪ **Cluster adjusted**	Not cluster RCT (N/A)	Not cluster RCT (N/A)	Not cluster RCT (N/A)
Intervention ▪ **Name or description** ▪ **Type**	▪ EXP: Modified Yokohama Baseball program as warm-up ▪ CON: Warm-up as usual	▪ EXP: FIFA 11+ injury prevention program replaces warm-up ▪ CON: Regular warm-up	▪ EXP: Strength training program as part of a warm-up ▪ CON: comparable handball training, without any additional specific strength training
Intervention ▪ **Frequency (total number)**	1 - 2 x a week for 12 months (52 - 104)	3x per week for one soccer season (August - December 2012) [64.5]	Performed 3 x per week for seven months. (90)
Intervention ▪ **Dose (total hours)**	10 min (8.67*h* - 17.33*h*)	20 Min (64.5*h*)	3 x 12 reps of high fatigue (3240 reps)
Intervention ▪ **Compliance (%)**	73.4% performed the program a mean 1.6 times per week.	Mean (+SD): 30.47 (+12.16) [47.24]	No data were available on team compliance in this study.
Intervention ▪ **Categorisation** ▪ **OKC vs CKC**	Predominantly targeting the upper extremity Total: n = 9 Upper extremity: n = 7 Mainly mobility and stretching (self-massage)	Incidentally targeting the upper extremity Total: n = 15 Upper extremity: n = 2 Mainly planking on arms for CKC	Exclusively targeting the upper extremity Total: n = 2 Upper extremity: n = 2
	Strength: 0	Strength: 0	Strength: 1 (36 reps)
	Flexibility: 3 (30 sec)	Flexibility: 0	Flexibility: 0
	Mobility: 3 (30 reps)	Mobility: 0	Mobility: 0

	Proprioception:	0	Proprioception:	0	Proprioception:	0
	Plyometrics:	0	Plyometrics:	0	Plyometrics:	1 (36 reps)
	Functional:	1 (10sec)	Functional:	2 (240 sec)	Functional:	0
	Multimodal:	0	Multimodal:	0	Multimodal:	0
	OKC vs CKC	OKC 2 (20 reps) vs CKC 5 (30sec + 20 reps)	OKC vs CKC	OKC 2 (240 sec) *vs* CKC 0	OKC vs CKC	OKC 0 vs CKC 2 (72 reps)
Outcome measure ▪ **Shoulder or upper extremity**	Specified shoulder + Elbow = Upper extremity		Specified shoulder + Arm + Elbow + Forearm + Wrist + Hand = Upper extremity		Specified shoulder	
Outcome measure ▪ **Number of injuries (EXP vs CON)**	Shoulder injuries: ▪ EXP: 9, CON: 17 Elbow injuries: ▪ EXP: 18, CON: 29 Upper extremity injuries: EXP: 27*, CON: 46*		Shoulder injuries: ▪ EXP: 6, CON: 30 Arm injuries: ▪ EXP: 1, CON: 1 Elbow injuries: ▪ EXP: 2, CON: 9 Forearm injuries: ▪ EXP: 0, CON: 1 Wrist injuries: ▪ EXP: 0, CON: 7 Hand injuries: ▪ EXP: 6, CON: 10 Upper extremity injuries: ▪ EXP: 15*, CON: 58*		Shoulder complaints: ▪ EXP: 66*, CON: 83*	
Outcome measure ▪ **Acute vs overuse**	Overuse injuries not investigated		Overuse injuries not investigated		EXP: n = 21 (40.4%) reported pain at baseline & n = 8 (17.4%) at post-test vs CON: n = 13 (24.5%) reported pain at baseline & n = 11 (26.8%) reported pain at post-test	
Outcome measure ▪ **Primary outcome**	Positive The incidence of shoulder & elbow injuries in the EXP (1.7 per 1000 AE) was significantly lower than CON (3.1 per 1000 AE), HR = 1.940; 95% CI 1.175-3.205; P = .010)		Positive The FIFA 11+ significantly reduced injury rates by 46.1% and decreased time lost to injury by 28.6% in the competitive male collegiate soccer player (RR = 0.54 [95% CI 0.49-0.59]; P < .0001)		No effect This study showed that a strength-training program did not prevent shoulder pain among junior female team handball players.	
Bias and main limitations	1. Participants and the physical therapist who trained them in the prevention program were not blinded to group allocation		1. The short duration of the season makes it challenging to impart the full neuromuscular benefit of such an intervention program 2. Researchers had to depend on electronic dissemination of medical information and		1. EXP group visited twice as much as CON at the beginning of the season 2. Pain is subjective, and many factors can influence the experience of pain 3. Learning and maturation effect of EXP group doing push-ups	

	2. The sample size was inadequate to investigate the effect on the incidence of elbow & shoulder injuries separately 3. Limited females in this study inadequate to examine any sex-specific differences 4. This program targeted all youth baseball players, not only pitchers	program implementation due to the vast geographic area	4. Data on personal characteristics of the players were not collected 5. Lack of compliance. None of the coaches handed over the compliance forms at the end of the season 6. Players filled in the questionnaires before handball training
Study	**Steffen *et al.***	**Verhagen *et al.***	**Wedderkopp *et al.***
Publication year	2008	2004	1999
Appraisal rating	53.84%	38.46%	15.39%
Country	Norway	Netherlands	Denmark
Setting ▪ **Sport**	Football	Volleyball	Handball
Setting ▪ **Level**	Youth (Under-17 league)	2nd & 3rd divisions	Elite teams (training 6 - 10 h per week), intermediate teams (training 3 - 6 h per week), recreational teams (training 2 - 3 h per week)
Population ▪ **Sex** ▪ **Age – Mean (SD)**	Females 13 - 17 yrs. EXP & CON: 15.4 (0.8) yrs.	Females & Males 21 - 27 yrs. EXP: 24.4 (2.8) yrs., CON: 24.2 (2.5) yrs.	Females Aged 16-18 yrs.
Sample ▪ **Sample size**	113 teams, n = 2100 ▪ EXP: 59 teams, n = 1100 ▪ CON: 54 teams, n = 1000	116 teams, n = 1127 ▪ EXP: 66 teams, n = 641 ▪ CON: 50 teams, n = 486	22 teams, n = 237 ▪ EXP: 11 teams, n = 111 ▪ CON: 11 teams, n = 126
Sample ▪ **Declined (%)** ▪ **Drop-out rate (%)** ▪	Declined participation: 44 teams (28.03%) Dropped out during study: ▪ EXP: n = 27 (2.45%) – *Incorrectly indicated as n = 18* ▪ CON: n = 53 (5.30%) – *Incorrectly indicated as n = 54*	Declined participation: 172 teams (59.72%) Dropped out during study: ▪ EXP: 18 teams, n = 249 (38.85%) ▪ CON: 12 teams, n = 193 (39.71%)	Not mentioned
Sample ▪ **Analysed (%)**	▪ EXP: 58 teams, n = 1073 (97.55%) ▪ CON: 51 teams; n = 947 (94.70%)	▪ EXP: 48 teams, n = 392 (61.15%) ▪ CON: 38 teams, n = 340 (60.29%)	Not mentioned
Sample ▪ **ITT/PP analysis**	ITT & PP	Not mentioned, missing exposure data was estimated	Not mentioned
Sample ▪ **Cluster adjusted**	Cluster adjusted (ICC 0.05) inflation factor 1.8	Not cluster RCT (N/A)	Not cluster RCT (N/A)
Intervention ▪ **Name or description** ▪ **Type**	the "11"' ▪ EXP: Replace warm-up with the 11 ▪ CON: Continued regular warm-up	▪ EXP: Balance board training program with one of four exercises added to warm-up. ▪ CON: Continued regular warm-up	▪ EXP: Warm-up programme, with particular emphasis on injuries in the lower extremities The utilisation of balance disc for balance training

			▪ CON: Warm-up as usual
Intervention ▪ **Frequency (total number)**	Every session for 15 consecutive sessions After that, once per week for eight months (50)	One of the prescribed exercises each warm-up for 36 weeks. Approximately four sessions per week (144)	All practice sessions for ten months – No data on the number of sessions
Intervention ▪ **Dose (total hours)**	15 Min warm-up with 5 min jog = 20 min (16.67*h*)	One exercise for approximately 5 minutes. (12*h*)	10 – 15 Minutes
Intervention ▪ **Compliance (%)**	Performed 23 (+/- 9) times (range 2–42) The program was used at 52% of all training sessions.	No data are available on an individual or team compliance.	Provides no specific exercises – program not divulged
Intervention ▪ **Categorisation** ▪ **OKC vs CKC**	Incidentally targeting the upper extremity Total: n = 10 Upper extremity: n = 5 Mainly planking and throwing the ball	Incidentally targeting the upper extremity Total: n = 21 Upper extremity: n = 17 (one sample used) Mainly throwing and passing	Incidentally targeting the upper extremity Total: n = 10 Upper extremity: n = 5 Mainly planking and throwing the ball
	Strength: 0	Strength: 0	Strength: N/A
	Flexibility: 0	Flexibility: 0	Flexibility: N/A
	Mobility: 0	Mobility: 0	Mobility: N/A
	Proprioception: 0	Proprioception: 0	Proprioception: N/A
	Plyometrics: 0	Plyometrics: 0	Plyometrics: N/A
	Functional: 2 (120 sec)	Functional: 0	Functional: N/A
	Multimodal: 3 (270 sec)	Multimodal: 1 (300 sec)	Multimodal: N/A
	OKC vs CKC: OKC 3 (270 sec) vs CKC 2 (120 sec)	OKC vs CKC: OKC 1 (300 sec) vs CKC 0	OKC vs CKC: N/A
Outcome measure ▪ **Shoulder or upper extremity**	Upper extremity	Specified shoulder & upper extremity	Specified shoulder + elbow + hand + finger = Upper extremity
Outcome measure ▪ **Number of injuries (EXP vs CON)**	Upper extremity injuries: ▪ EXP 30, CON 37 Incidence of the upper extremity: ▪ EXP 0.5 (0.3 - 0.6) vs CON 0.6 (0.4 - 0.7) ▪ Upper extremity Rate ratio EXP vs CON 0.8 (0.5 - 1.3)	Acute shoulder injuries: ▪ EXP: 6, CON: 2 Acute upper extremity injuries: ▪ EXP: 16, CON: 9 Overuse shoulder injuries: ▪ EXP: 7 vs CON: 9 Overuse upper extremity injuries: ▪ EXP: 1 vs CON: 0	Shoulder injuries: ▪ EXP: 2, CON: 0 Elbow injuries: ▪ EXP: 0 vs CON: 9 Hand injuries: ▪ EXP: 0 vs CON: 1 Finger injuries: ▪ EXP: 2, CON: 10 Upper extremity injuries: ▪ EXP: 4*, CON: 20*
Outcome measure ▪ **Acute vs overuse**	No specified overuse data Overall injuries were mostly acute (87%) and located in the lower extremities (86%)	Measured	No specified overuse data Overall overuse injuries: ▪ EXP: 1 vs CON: 8

Outcome measure ▪ **Primary outcome**	Inconclusive No difference was observed in the overall injury rate between the intervention (3.6 injuries/1000 h, CI 3.2 - 4.1) and control group (3.7, CI 3.2 - 4.1) RR=1.0 (CI 0.8-1.2; P=0.94) nor in the incidence for any type of injury	Positive Significantly fewer ankle sprains in the EXT vs CON (risk difference = 0.4/1000 playing hours; 95% CI, 0.1-0.7)	Compared to the control group, the intervention group had significantly fewer injuries both during (80%) games and practice (71)
Bias and main limitations	1. Poor compliance 2. All of the ten exercises in this program without progression or variation and may have resulted in reduced motivation among coaches and players 3. Exercises based on football prevention programs 4. Individual exposure data were not recorded and thus not possible to perform a sub-group analysis on an individual level	1. No concrete information on how the coaches and players complied with the intervention program 2. Injury awareness is believed to be a confounding factor in sports injury research 3. Self-reporting increases chance of recall bias 4. Nonresponses indicates high selection bias	1. Changes about injury prevention awareness may have changed training practices influencing the injury incidence observed in the control group 2. Difficulty in registering overuse injuries due to recall bias

EXP – Experimental group; CON – Control group; SD – Standard deviation; yrs. – years; IPP – Injury prevention programme F – Female; M – Male; ICC – Intraclass correlation coefficient; ITT – Intention-to-treat; PP – Per protocol; *h* – hours; min – minutes; sec – seconds; reps – repetitions; CI – Confidence interval; AE – Athletic exposure; RCT – Randomised Controlled Trial; HR – Hazard ratio; IRR – Injury risk ratio; RR –Relative risk
*Calculated from raw data ** Information provided by the author

Appendix F: PRISMA checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	i
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	iv
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	1, 6
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	8
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	73
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	74
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	78
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Appendix A
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	78
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	80
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	81

Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	79
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	81
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	82

Section/topic	**#**	**Checklist item**	**Reported on page #**
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	79, 81
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	80
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	86
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	89
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	86, 91
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	93
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	96
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	108
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	97
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	109, 119
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	135, 143

Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	142
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	81

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

Appendix G: Turnitin report

Turnitin Originality Report

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