Liddle, N, Taylor, JM, Chesterton, P and Atkinson, G

The effects of exercise-based injury prevention programmes on injury risk in adult recreational athletes: A systematic review and meta-analysis

Title: The effects of exercise-based injury prevention programmes on injury risk in adult recreational athletes: A systematic review and meta-analysis.

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Authors: Nathan Liddle[1], Jonathan M. Taylor[1], Paul Chesterton[1], Greg Atkinson[2]

Affiliations: [1]School of Health and Life Sciences, Teesside University, Middlesbrough, UK. [2]School of Sport and Exercise Science, Liverpool John Moores University, Merseyside, UK

Correspondence: Nathan Liddle
Teesside University, Middlesbrough
United Kingdom
TS1 3BA
N.Liddle@tees.ac.uk

Abstract

Background

Injuries are common in adult recreational athletes. Exercise-based injury prevention programmes offer potential to reduce the risk of injury and have been a popular research topic. Yet, syntheses and meta-analyses on the effects of exercise-based injury prevention programmes for adult recreational athletes are lacking.

Objectives

To synthesise and quantify the pooled intervention effects of exercise-based injury prevention programmes delivered to adults who participate in recreation sports.

Methods

Studies were eligible for inclusion if they included adult recreational athletes (>16 years old), an exercise-based intervention, and used a randomised controlled trial design. Exclusion criteria were studies without a control group, studies using a non-randomised design, and studies including participants who were undertaking activity mandatory to their occupation. Eleven literature databases were searched from earliest record, up to 9th June 2022. The PEDro scale was used to assess the risk of bias in all included studies. Reported risk statistics were synthesised in a random-effects meta-analysis to quantify pooled treatment effects and associated 95% confidence (CI) and prediction (PI) intervals.

Results

Sixteen studies met the criteria. Risk statistics were reported as risk ratios (RR) (n=12) or hazard ratios (HR) (n=4). Pooled estimates of RR and HR were 0.94 (95%CI: 0.80-1.09) and 0.65 (95%CI: 0.39-1.08) respectively. PIs were 0.80-1.09 and 0.16-2.70 for RR and HR respectively. Heterogeneity was very low for RR studies, but high for HR studies (tau = 0.29,

I^2=81%). There was evidence of small study effects for RR studies, evidenced by Funnel plot asymmetry and Egger's test for small study bias: -0.99 (CI: -2.08 to 0.10, P=0.07).

Conclusion

Pooled point estimates were suggestive of a reduced risk of injury in intervention groups. Nevertheless, these risk estimates were insufficiently precise, too heterogeneous, and potentially compromised by small study effects to arrive at any robust conclusion. More large-scale studies are required to clarify whether exercise-based injury prevention programmes are effective in adult recreational athletes.

Registration

The protocol for this review was prospectively registered in the PROSPERO database (CRD42021232697).

KEY POINTS

- INJURY PREVENTION PROGRAMMES MAY HAVE THE POTENTIAL TO REDUCE THE RISK OF INJURY FOR ADULT RECREATIONAL ATHLETES
- EFFECTIVENESS OF EXERCISE-BASED PROGRAMMES IS NOT CLEAR FROM CURRENT EVIDENCE
- ADDITIONAL AND LARGER RANDOMISED CONTROLLED TRIAL STUDIES ARE REQUIRED

1. Background

Participation in physical activity and exercise is recommended worldwide [1], with the positive effects of physical activity well established within the research literature [2]. Conversely, an increase in physical activity, specifically participation in sports, increases the probability of musculoskeletal injuries [3]. Injury incidence rates vary between sports, with 13.8 injuries per 1000 hours of training and competition reported in rugby [4] and 2.5 injuries per 1000 hours reported in runners [5]. Therefore, while sports participation should be encouraged given the health benefits it provides [2], it comes with an increased injury risk.

The physical impact of musculoskeletal injuries can be profound. Specifically, in non-elite and recreational populations, injuries can affect other facets of life, such as a person's ability to work, or to be able to effectively care for family members [6]. Furthermore, in these populations, the consequences of injuries resulting from sports participation are likely to burden health providers, such as the National Health Service (NHS) in the UK. Whilst the economic burden of sports injuries to the NHS has not been assessed to date, the burden of running-related injuries in Dutch runners is estimated to be >€170 per injury due to a combination of direct costs (healthcare) and indirect costs (missing paid work) [7]. Therefore, strategies that can reduce injury risk have potential to minimise the financial burden placed on recreational individuals and health providers.

Injury prevention programmes are by nature designed to reduce injury risk in sports participants and there are various examples within the scientific literature. The International Federation of Association Football (FIFA) 11+ is one such programme that gained popularity in sub-elite soccer [8]. The popularity of the FIFA 11+ is largely due to the simplicity of the protocol and the limited equipment required, making it accessible and easy to perform [9]. Similarly, the 'Foot Core' injury prevention programme was developed for runners and was shown to reduce running related injuries [5]. Meanwhile, Finch et al. [10] used various running and change-of-direction drills as the basis of their neuromuscular control programme to prevent injuries in Australian Rules Football, and this showed some potential in reducing lower limb injuries. The effectiveness of these studies demonstrates the potential of such programmes to reduce injury across sports, across different athlete demographics.

Although the evidence supporting the use of injury prevention programmes continues to grow, there is variability in the interventions prescribed. The studies on this topic are sometimes characterised by small sample sizes, inconsistent reporting of intervention dosage or duration, and imprecision when reporting outcomes. Despite the potential shown in various studies [5, 11] and single sports [9], there is little consensus on the effectiveness of exercise-based injury prevention strategies to reduce injury risk across various sports in the adult population. This must be appreciated given the injury patterns/types associated with different sports and consequently the variability in the design principles of sport specific prevention programmes. The effectiveness of such intervention strategies in 'recreational athletes' has not been examined in-depth. This is highly relevant given the mass participation in sports by 'recreational athletes' often with limited access to expensive treatment options, and where prevention might be deemed of greater importance to longer term health outcomes [2]. Therefore, research aiming to draw consensus on this seems necessary.

The aim of this study was to systematically review and meta-analyse the effects of exercise-based injury prevention programmes on the prevention of injuries amongst adult recreational athletes. Here adult recreational athletes were defined as individuals undertaking a sport or physical activity that is not related to their profession or occupation.

2. Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 guidelines were followed during this study. The protocol for this review was prospectively registered in the International prospective register of systematic reviews (PROSPERO) database (CRD42021232697).

2.1 Eligibility Criteria

Only randomised controlled trials investigating the effectiveness of exercise-based programmes compared with a control group for preventing injuries in adult recreational athletes were included. An exercise-based prevention programme was defined as any exercise therapy that was physically performed by the participant on an individual or group basis. Control groups were considered as usual training/warm-up, minimal intervention, education or not exposed to the intervention. Studies were eligible if they; included adult recreational athletes (>16 years old), used exercise-based programmes as intervention, used a randomised method for allocating interventions and had a control group. All types of exercise-based prevention programmes were eligible for inclusion. Exclusion criteria were studies without a control group, studies using a non-randomised design, and studies including participants who were undertaking activity mandatory to their occupation.

2.2 Information Sources

The search for relevant studies was performed in eleven electronic sources (Web of Science, EBSCOhost, (Medline, AMED, and CINAHL), Cochrane Library online, EMBASE, Scopus, PubMed, clinicaltrials.gov and dissertations indexed with ProQuest Dissertations and Theses Global and EthOS) from the earliest available record to the 9th June 2022.

2.3 Search Strategy

The implemented search strategy used a Participant, Intervention, Comparison, Outcome (PICO) format. The search terms used were; P – athlete* OR player* OR sport*, AND I – prevent* AND intervent*, AND C – (randomi* AND control* AND trial*) OR RCT, AND O – injur*. The reference lists of previous similar systematic reviews were checked to find potential studies for inclusion. There was no restriction regarding language of publication. The full search strategy can be viewed in Supplementary File 1.

2.4 Selection Process

The lead author (NL) applied the inclusion criteria in the first instance and screened studies based upon title alone. Titles and abstracts were then collaboratively evaluated by NL and JT, with a third opinion sought from GA if there were any queries. Full texts were then read by 3 authors (NL, GA, JT) and a consensus was reached regarding which studies were to be taken forward to the meta-analysis stage.

2.5 Data Collection Process

Data extraction was initially performed by a single author (NL). The following information was extracted from each eligible study: participants' characteristics (i.e., age & sex), sample size (total and per group), characteristics of the intervention (focused or general exercises), participants' sport, number of injuries and exposure hours for each group, and study length.

Interventions were categorised by the authors of the current review as general when the exercises targeted multiple areas of the body or multiple joints, with no specific area, joint or muscle prioritised. Focused interventions were defined as those that aimed to reduce the risk of injury to a specific muscle or joint. This approach was used in a recent systematic review by Lemes at al. [12].

2.6 Risk of Bias and Grade Assessments

The Physiotherapy Evidence Database (PEDro) scale was used to assess the bias of all included studies, via the extraction of data from the online PEDro database. Prior to extraction of the data from the online database, the lead author (NL) manually extracted the information from each included study individually. Once extraction from the online database was completed, a cross-referencing process was conducted to ensure agreement between manually extracted data and data extracted from the database. NL conducted the risk of bias assessment independently initially, with JT conducting a risk of bias assessment on the only study unavailable on the PEDro database [13] following a recommendation made during the peer-review process. Second opinion was sought from GA concerning any queries relating to the risk of bias assessment. The PEDro scale is a reliable measure for assessing the methodological quality of randomised controlled trials (RCTs) [14]. More recent evidence has also demonstrated acceptable levels of convergent and construct validity, in addition to acceptably high interrater reliability [15].

The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach was used to assess the overall quality of studies included. This approach allows a judgement to be made regarding the certainty of evidence produced from systematic reviews [16]. The GRADE approach is a systematic process that allows assessments to be made regarding the strength of evidence reported in systematic reviews. As the current study included only randomised controlled trials, the evidence was initially regarded as 'high'. Subsequently the strength of the evidence was downgraded by one level for each of the following domains; (1) risk of bias (when more than 25% of studies included in the meta-analysis were from studies with 'high risk of bias' (ie, <6/10 on the PEDro scale); (2) inconsistency (when considering: the proportion of the observed variance may be substantial (I^2>50%), visual inspection for minimal or no overlap of CIs, and x^2 test (p value <0.05); (3) indirectness (downgraded by one level if meta-analysis included participants with heterogeneous characteristics); (4) imprecision (downgraded by one level when the clinical course of action differed considering the upper and lower CI as the true estimate); and (5) publication bias (assessed funnel plot asymmetry by visual inspection), if there were at least 10 studies in the meta-analysis) [16].

Four categories are used to describe the quality of the evidence reported: high quality (the authors have a lot of confidence that the true effect is similar to the estimated effect); moderate quality (the authors believe that the true effect is probably close to the estimated effect); low quality (the true effect might be markedly different from the estimated effect); and very low quality (the true effect is probably markedly different from the estimated effect).

2.7 Statistical Analysis

Where reported, multivariable-adjusted risk statistics (and associated confidence limits) were extracted from the included studies. For some studies, the number of injuries and exposure hours were used to calculate the risk ratio. In one study [5], the reported hazard ratio was calculated using the intervention group rather than the control group as the baseline risk, so this hazard ratio was reciprocated prior to analysis. Reported risk statistics were risk ratios and hazard ratios (when a survival analysis approach was used).

Risk and Hazard ratios were natural log-transformed prior to analysis, as recommended in the Cochrane Handbook [17]. Pooled risk ratios and hazard ratios, as well as associated 95% confidence intervals (CI) and prediction intervals (PI), were quantified in weighted meta-analyses, using the inverse variance approach using Stata Version 16 (StataCorp. 2019. Stata Statistical Software: Release 16. College Station, TX: StataCorp LLC). Random effects models were selected with a Restricted Maximum Likelihood (REML) estimator and the Knapp-Hartung adjustment [18]. 95% Prediction intervals were also calculated because PIs are much more consistent with the appropriate interpretation of a random effects meta-analysis [18]. I-squared (I^2) and Tau statistics were calculated to quantify heterogeneity. Tau was reported because of the recent concerns about the I-squared statistic [19]. Funnel plots were used to assess small study bias (publication bias). A statistical test (Egger's intercept) for funnel plot asymmetry was performed where appropriate [20].

2.8 Deviations from PROSPERO protocol

Minor deviations from the original PROSPERO protocol submission were implemented (CRD42021232697). The original inclusion criteria were 'RCTs, clinical trials, and cohort studies; studies using quantitative methodologies'. However, other elements of the inclusion criteria were included elsewhere in the PROSPERO submission under subheadings of 'participants' and 'intervention'. For the Risk of Bias (RoB) assessment, the Cochrane RoB 2 tool was originally proposed, however, the PEDro scale was used due to the convenience and clarity of the scale and specific suitability for our review [12].

We also initially proposed a meta-regression to enhance the understanding of mechanisms relating to injury prevention such as; male-female comparison, age, intervention duration, and training frequency. However, during data extraction it became clear that there was insufficient data to perform reliable and effective meta-regressions or sub-group analyses.

Figure 1 – Search, screening, and eligibility process near here.

3. Results

Study selection

Our search, screening and eligibility process is displayed in Figure 1. A total of 11362 studies were identified, with 11087 excluded following initial screening. Further screening by title and abstract led to the exclusion of 244 studies, and following full screening of the remaining 31 studies, 16 were retained for analysis.

3.1 Study characteristics

Study characteristics for the analysed studies are displayed in Table 1. Most studies were conducted in Europe (n=10), whilst Australia (n=2), Brazil (n=1), Canada (n=1), and Iran (n=1) accounted for 5 studies, and one study was conducted worldwide. The studies focussed on a variety of sports including soccer (n=9), running (n=3), Australian Football League (AFL) (n=2), volleyball (n=1) and general physical activity (n=1). General physical activity was defined as taking part in vigorous physical activity on at least 1 day per week [21]. Examples of vigorous physical activity include jogging and running [22], and team sports including soccer and rugby [23]. Only 4 studies recruited male and female participants, with 10 including only male participants and 2 including only female participants. Ten studies reported injury in general terms, with 6 reporting specific injuries (hamstring n=4, groin n=1, ankle sprain n=1).

Table 1 – Characteristics of included studies near here

3.2 Risk of bias & quality assessment

Risk of bias for the included studies is presented in Table 2. The majority of included studies (n=13) were rated 'fair' quality (scoring 4-5 on the PEDro scale), 2 studies were rated 'good' quality (6-8 on the PEDro scale), and one study was rated as 'poor' (>4/10 on the PEDro scale). The rating categories have been previously described by Foley et al. [24]. Only 4 studies reported concealed allocation, due to the nature of the interventions prescribed. Participant and therapist blinding was not possible given the nature of the exercise-based interventions. Furthermore, only one study [5] reported assessor blinding. Just under half (n=7) reported adequate follow-up as per the PEDro scale. The PEDro scale outcomes were taken directly from the PEDro database, apart from one study [13], which was not present within the database. The outcome of the GRADE for analysed studies is displayed in Table 3. The certainty of our evidence was classified as 'very low', meaning 'The true effect is probably markedly different from the estimated effect'. Of the included studies, 6 used a cluster-randomised design [8, 10, , 25,26, 27, 28]. However, only 2 studies [10, 25] reported the intra-cluster correlation coefficient, a statistical measure to achieve the equivalent power of non-clustered randomised trials [29].

Table 2 – PEDro scale assessment of included studies near here

Table 3 – Grade Assessment near here

3.3 Results of syntheses

Risk statistics were reported as risk ratios (RR) (n=12) (Figure 2) or hazard ratios (HR, n=4) (Figure 3). The pooled point estimate of studies reporting RR was 0.94 (95% CI: 0.80,1.09), which was not statistically significant (P=0.35). Moreover, the generally low quality of evidence must also be considered when interpreting this pooled estimate (Figure 2). During the peer-review process for our study, concern was levelled at the suitability of the study by Espinosa et al. [13]. Therefore, we ran a sensitivity analysis without this study in the meta-analysis. The resulting RR of 0.94 (95%CI: 0.81, 1.09) was the same as that obtained in our primary analysis. This study was particularly small in sample size and number of reported injuries. It, therefore, was allocated a very small weight in the calculation of pooled RR.

The pooled point estimate of studies reporting HR (n=4) was 0.65 (95% CI: 0.39, 1.08). This pooled point estimate was not statistically significant (P=0.07) and, again, the very low quality of evidence must also be considered when interpreting this estimate (Figure 3). Heterogeneity of the pooled RR studies was very low (I^2 = 0%), heterogeneity of between 0-40% has been reported as 'might not be important' previously by Higgins et al. [17]. Heterogeneity of the studies reporting HR was 'considerable' (tau = 0.29; I^2 = 81.43%) according to previously reported thresholds by Higgins et al. [17]. Evidence of small study effects for RR studies, evidenced by Funnel plot asymmetry and Egger's test -0.99 (95%CI: -2.08 to 0.10, P=0.07). (Figure 4).

Figure 2 – Forest plot of studies using Risk Ratio data.

Figure 3 – Forest plot of studies using Hazard Ratio data.

Figure 4 – Risk Ratio Funnel Plot

4. Discussion

This aim of this study was to systematically review and meta-analyse the effects of exercise-based injury prevention programmes on injury risk amongst adult recreational athletes from a variety of sports. While pooled point estimates of RR and HR favoured the intervention groups in terms of a lower risk of injury, the current evidence is insufficiently precise, very low in quality, and too heterogeneous to arrive at any robust conclusions regarding effectiveness. Most notably, the wide 95% prediction intervals suggests that the effect size in any individual future study could indicate a lower or even a higher risk of injury in the intervention group. Heterogeneity across studies which assessed RR was low, however high heterogeneity in studies reporting HR indicates high variability amongst studies exploring exercise-based injury prevention programmes. Therefore, there is insufficient evidence to indicate that the various interventions led to a lower risk of injury.

Though this review provides a novel synthesis of the effects of exercise-based injury prevention programmes in adult recreational populations across sports, the impact of neuromuscular training on injury risk in children and adolescent athletes has been synthesized in previous reviews. Interestingly, there is a growing consensus amongst published work that contrasts the results from our review for injury prevention programmes, albeit specific to adolescent/youth athletes [30, 31, 32, 33]. Hubscher et al. [32] reported that studies on 'multi-intervention' training indicated a pooled reduction of 39% (0.61; 95% CI: 0.49, 0.77) in injury risk. It should be noted that injury prevention literature including children or adolescent populations has shown favourable results compared to that demonstrated within our review [30, 31, 33]. Although those findings may not agree with ours, they may be explained by differences in the study participant groups i.e., adult vs child populations. For example, previous injury is an important risk factor for subsequent injury [34], and the children and adolescent athletes reviewed in Hubscher et al. [32] and others [30, 31, 33] may have been less likely than adults to have incurred injury previously due to reduced cumulative exposure to sporting activity. Unfortunately, we were unable to undertake a meta-regression of age as a moderator of RR or HR due to the small number of studies. Nevertheless, we scrutinised qualitatively the individual studies for any general picture of age influences. For example, Sadigursky et al. [9] concluded that the FIFA 11+ reduced injury risk in soccer players aged >13 to 25 years by 30%. Lemes et al. [12] reported a reduction in non-contact musculoskeletal injury risk of 23%. In contrast, Hammes et al. [8] studied players older than 40 years and reported no reduction of injury risk following a FIFA 11+ intervention, which may suggest that older participants may not respond as favourably to injury prevention programmes. This is potentially significant given that athletes aged ≥30 years have been reported to have a 4-5-fold increased risk of tendon, bone, or muscle injury compared to those aged <30 years [35]. Moreover, a recent Delphi study by Mendonca et al. [36] of experienced sports Physical Therapists concluded that participant age is an important factor when considering the implementation of an exercise-based injury prevention programme.

Given the popularity of the FIFA 11+ amongst researchers exploring injury risk in soccer, this intervention is worth considering in more detail. Al Attar & Alshehri [37] conducted a meta-analysis of meta-analyses. Four meta-analyses were analysed with a combined overall injury risk reduction of 34% (RR = 0.66; 95% CI: 0.6, 0.73), and a reduction in lower-limb injuries of 29% (RR = 0.71; 95% CI: 0.63, 0.81). Given the number of participants across the included meta-analyses (n = 7268), the 2019 analysis [37] is a substantial contribution to the evidence base of exercise-based injury prevention. The meta-analysis included studies that recruited a combination of youth and adult participants, and this must be considered when interpreting their results. As previously discussed, there are contrasting results when comparing the effectiveness of injury prevention programmes between adults and adolescents/youth athletes. The effectiveness of the FIFA 11+ in reducing injury risk of ~30% (RR = 0.70) is considerably higher than in other individual RCTs. Differences between studies may, again, relate to participant characteristics. The FIFA 11+ has also been designed specifically to address the most common soccer injuries sites i.e., thigh, knee, or ankle [38]. Other sports demonstrate varying injury epidemiology, and likely require different programme elements. Despite this, the evidence presented by Attar and Alshehri [37], demonstrates the potential benefits of exercise-based injury prevention programmes for other sports/physical activities, and provides a 'blue-print' for the design of other sport-specific programmes. We also highlight the fact that many previous systematic reviewers did not report prediction intervals for their pooled treatment effects. Prediction intervals are much more aligned to the correct interpretation of a random effects meta-analysis and tend to be wider than confidence intervals.

Our findings indicate that, all studies considered, exercise-based injury prevention programmes may not be successful at reducing the risk of injury. Understanding the mechanisms which mediate the success of exercise-based injury prevention programmes is critical to further enhance this area of research. Several themes can be observed across the various exercise-based prevention programmes used within the literature. Van der Horst et al. [28] evaluated the effectiveness of the Nordic hamstring exercise (NHE), while Finch et al. [10] included 'Neuromuscular Control' exercises within their intervention, including the use of single leg standing exercises to facilitate balance. Alternatively, Van de Hoef et al, [27] reported the effectiveness of a bounding programme within their intervention. The NHE, single leg standing exercises, and bounding exercises are all elements included within the FIFA 11+. The identification of commonalities within successful exercise-based injury prevention programmes may support the development of future programmes.

Although injury-prevention is multi-factorial, it appears that specificity is important when developing an effective injury prevention programme. Besides the FIFA 11+ soccer-specific injury prevention programme, Gouttebarge et al. [11] demonstrated a reduction in injury risk (HR 0.82 (95%CI: 0.69, 0.98)) after assessing a volleyball specific injury prevention programme. Their 'VolleyVellig' intervention was an exercise-based injury prevention programme targeting overuse injuries specific to volleyball, including ankle and knee injuries [11]. Taddei et al. [5] demonstrated a reduction in injury risk of 59% in their study of runners, with their exercise programme focussed on movements that activate specific muscles of the foot/lower leg region. Their specific aim was to disperse force whilst running throughout the musculature of the foot, aiming to reduce the overload of tissues commonly affected by running.

Another consideration of successful exercise-based injury prevention programmes is adherence. Regardless of the design or specificity of a programme, if adherence is poor, it cannot be successful. There were 4 studies included in our analysis that did not report adherence, which presents difficulty when interpreting their data. Of the remaining 12 studies, 6 used a team coach or member of the study team to record adherence, 5 used a self-reporting mechanism, and one study used a web-based platform in combination with global positioning system technology. Although incomplete adherence data presents a challenge when trying to synthesise information, self-reported adherence levels may also present an inherently biased and often overestimated perception of the level of adherence to an intervention [39].

An example of the relative influence of adherence can be observed in Gabbe et al. [40], who explored the effectiveness of the NHE in community AFL players and reported 'poor adherence' in their intervention group with adherence falling by ~50%. Their participants reported that the NHE gave them delayed onset muscle soreness (DOMS), which reduced their desire to adhere. Similarly, Baltich et al. [41] reported a 51% adherence rate in the intervention group within their study. Participants in their 'functional strength' group completed their protocol 4 times per week and exercises included lunges, squats, hops, jumps, and single leg standing. Consequently, Gabbe et al. [40] and Baltich et al. [41] reported increased injury risk for the intervention groups in their studies which confounds confidence in their conclusions. Conversely, Taddei et al. [5] reported an 88% adherence rate, and a large reduction in injury risk. Further evidence of the link between adherence and injury prevention has been highlighted previously by several authors [39, 42, 43]. Verhagen et al. [43] performed a 'per protocol' analysis of previously collected data and reported an 82% (HR = 0.18; 95% CI: 0.07, 0.43) reduction in injury risk when comparing fully adherent participants to the control group. This is further supported by Steffen et al. [42] who concluded that a 'high' adherence group (271.2 FIFA11+ exercises completed during the study period) had a 57% lower injury rate than the 'low' adherence group (71.3 FIFA11+ exercises completed during the study period). Halvorsen et al. [39] concluded that although adherence levels were associated with reduced injury risk for ACL injuries, there was no significant link between adherence rates and general lower extremity injuries. It should be noted however, that groups of all levels of adherence included by Halvorsen et al. [39] demonstrated a pooled RR of 0.75 (95% CI: 0.6, 0.93) for lower extremity injuries demonstrating the potential protective effects of injury prevention programmes. Despite this, much of the evidence supports the notion that adherence rate seems critical to the success of exercise-based injury prevention programmes, and consideration of barriers and facilitators to adherence is fundamental to programme success.

Recently, Van der horst et al. [44] explored reasons behind non-adherence and suggested that knowledge of an injury prevention programme, proof of the effectiveness/success of an injury prevention programme, and personal motivation could all be linked to improving adherence. Although more evidence is needed regarding the complex nature of adherence, the study by van der Horst et al. [44] could provide future researchers with a starting point when trying to design an injury prevention programme for maximum adherence.

An important difference within the studies of this meta-analysis is the distinction between RR and HR data. The results of the studies reporting HR showed a larger effect size (0.65; 95% CI: 0.39, 1.08) than studies reporting RR (0.94; 95% CI: 0.8, 1.09), although the wide confidence and prediction intervals associated with the point estimates of RR and HR limit the precision of this comparison. Studies reporting HR include a survival analysis, which provides more information and higher statistical power. A survival analysis provides greater context as there is a clear 'time-to-event' consideration throughout the study period, compared to the studies reporting RR that only report that an event has occurred [45]. Therefore, including a survival analysis could be recommended for future injury prevention research, providing more robust data.

Our review is not without limitations. Firstly, several of the analysed studies used small sample sizes which influenced the statistical power of these studies. However, the weighted nature of the meta-analysis aimed to reduce the impact of smaller studies of the overall analysis. Secondly, the inclusion of sports which were contact (n=11) and non-contact could confound some of our analysis (i.e., underestimate the beneficial effect of programmes on non-contact injury) given the relatively high injury risk in contact sports [4] and the failure of some studies to report which injuries were contact related. The inclusion of those studies was based upon the breadth and quality of research available and the lack of high-quality evidence including only non-contact sports led to the necessity to include all sports. Methodologically, the screening process should ideally have been completed by two individuals working independently [17], though in our review the title screening process was conducted only by the lead author (NL). Although the screening of abstracts was completed by two individuals, and the Cochrane Handbook for Systematic Reviews of interventions states that "…it is acceptable that this initial screening of titles and abstracts is undertaken by only one person", [17] we accept that having two individuals screening titles would have been preferential. Finally, a lack of consistency across the studies used within the current review with respect to intervention type, length and dosage was observed. This is likely due to the inclusion of multiple sports but may be considered a strength in relation to the research and clinical significance. The inclusion of multiple sports provides a comprehensive, generalisable results compared to previous reviews that have considered single-sport injury prevention programmes which often have limited transfer. Whilst this makes identifying common components of effective programming more challenging, it demonstrates the need for further work.

5. Conclusion

The use of exercise-based injury prevention programmes is a growing research area given the prevalence of injury in athletes at all levels. Our primary finding was that there is insufficient evidence to support the idea that exercise-based injury prevention programmes are effective in reducing injury risk for adult recreational populations. Our review is the first to synthesise the effects of exercise-based injury prevention programmes in a variety of sports, involving adult recreational participants. Our results support the need for further development and appropriate implementation of exercise-based injury prevention programmes by practitioners, specifically in sports other than soccer. Researchers might concentrate on larger studies and programmes for non-contact sports such as running, which is a highly popular recreational activity but has received limited attention in the scientific literature. Furthermore, the development of programmes that focus on high reward for little time commitment presents a potential strategy to enhance adherence. Given the added information and statistical precision that time-to-event survival analyses offer, future research may also benefit from adoption of this design and analysis approach.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

Nathan Liddle, Jonathan Taylor, Greg Atkinson and Paul Chesterton declare that they have no competing interests.

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Authors' contributions

NL was the main author of the manuscript and responsible for the conception, design, and writing of the work. JT was involved with the design of the work and performed substantial revisions and improvements to the work. GA was responsible for the analysis and interpretation of the data and provided revisions and improvements to the work. PC was also involved in the design of the work and performed revisions and suggested improvements to the work. All authors read and approved the final manuscript.

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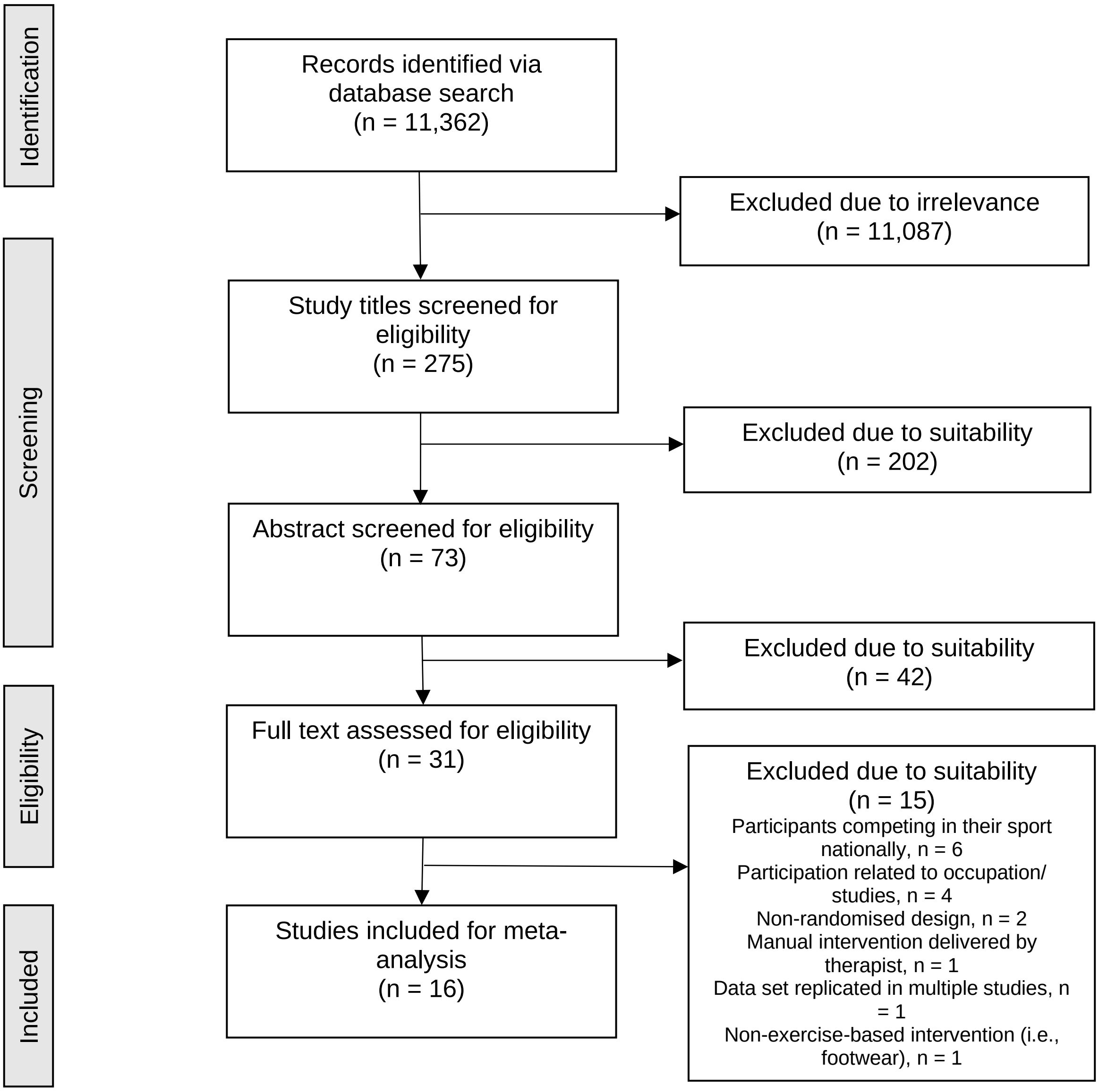

Figure 1. Flow Chart of included studies

Figure 2. Risk Ratio Forest Plot

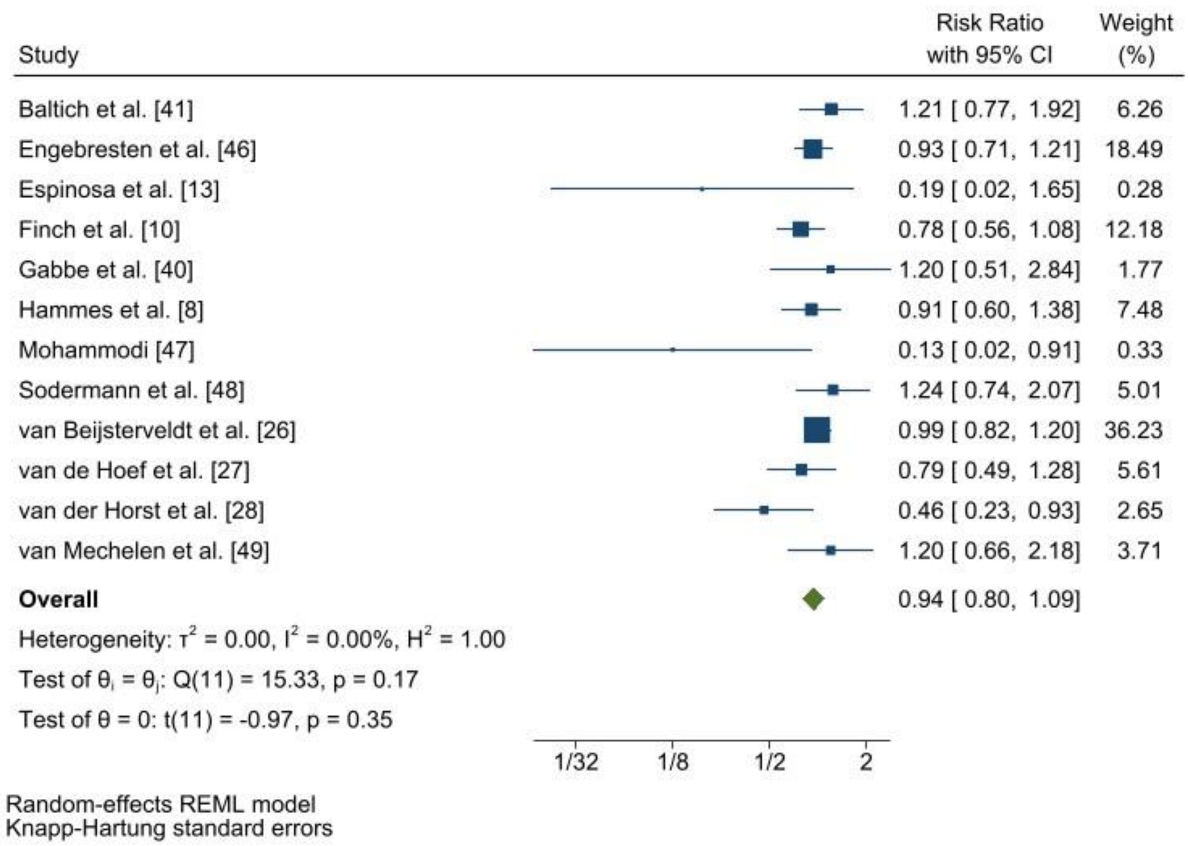

Figure 3. Hazard Ratio Forest Plot

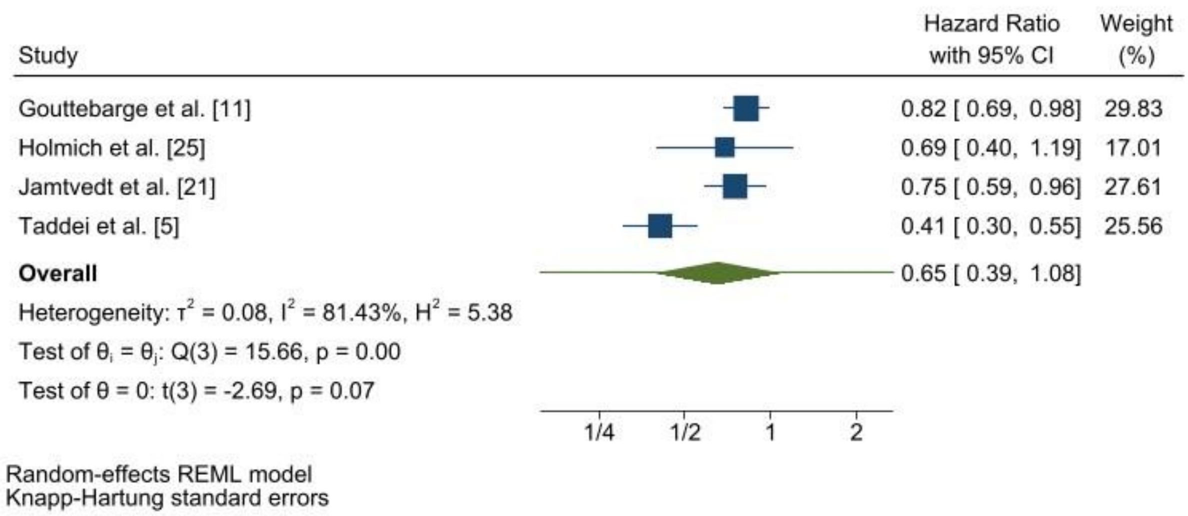

Table 1. Study Characteristics

Study, year	Country	Sport	Mean Participant Age (Years)	Participant Sex (m/f, %)	Sample Size	Intervention	Outcome	How adherence measured?
Baltich et al, 2017 [41]	Canada	Running	32	IG: 9/91 CG: 19/81	IG: 23 CG: 21	Progressive, 20 minute functional strength training for 8 weeks. 3-5 x per week for initial 8 weeks, twice per week for final 16 weeks	Running injuries	Self reported
Engebresten et al, 2008 [46]	Norway	Football/ soccer	X	Male only	IG: 193 CG: 195	Targeted exercise programme (based on injury history) 3 x per week for 10 weeks	Overall injuries	Self reported
Espinosa et al, 2015 [13]	Spain	Football/ soccer	21.3	Female only	IG: 22 CG: 21	Progressive eccentric hamstring programme prior to every training session for 21 weeks	Hamstring injuries	Coach
Finch et al, 2016 [10]	Australia	Australian Football	X	Male only	IG: 679 CG: 885	20 minute neuromuscular control programme,	Overall injuries	

						twice per week for duration of trial		
Gabbe et al, 2006 [40]	Australia	Australian Football	23.7	Male only	IG: 114 CG: 106	5 x Nordic hamstring exercise sessions over a 12 week period	Hamstring injuries	Member of the research team
Gouttebarge et al, 2020 [11]	Holland	Volleyball	28.5	IG: 38/62 CG: 24/76	IG: 348 CG: 324	"VolleyVeilig" - 15 minute exercise-based warm-up	Overall injuries	Coach
Hammes et al, 2015 [8]	Germany	Football/ soccer	44.2	Male only	IG: 146 CG: 119	FIFA 11+ at every training session	Overall injuries	Coach
Holmich et al, 2010 [25]	Denmark	Football/ soccer	24.5	Male only	IG: 477 CG: 420	13 minute hip & groin specific warm-up routine before every football practice	Groin injury	
Jamtvedt et al, 2010 [21]	Worldwide	General physical activity	39.9	IG: 37.5/62.5 CG: 35.3/64.7	IG: 1220 CG: 1157	14 minute+ lower-limb stretching routine	Overall Injuries & Soreness	Self report
Mohammodi 2007 [47]	Iran	Football/ soccer	24.6	Male only	Pooled data only: 80	Orthosis, 30 minute proprioception training, peroneal	Ankle inversion sprains	

						strengthening exercises - completed daily		
Sodermann et al, 2000 [48]	Sweden	Football/ soccer	20.5	Female only	IG: 62 CG: 78	15 minutes balance board training - every day for 30 days, then 3 x per week for remainder of the season	Traumatic lower-limb injuries	
Taddei et al, 2020 [5]	Brazil	Running	40.9	IG: 54/46 CG: 49/51	IG: 57 CG: 61	12 exercises targeting the foot-ankle muscles, 3 x per week for 12 months	Running-related injuries	Web software. GPS & running apps
van Beijsterveldt et al, 2012 [26]	Holland	Football/ soccer	24.8	Male only	IG: 223 CG: 233	"The 11" Injury prevention programme - 10 exercises at least twice per week	Overall injuries	Coach
van de Hoef et al, 2019 [27]	Holland	Football/ soccer	22.9	Male only	IG: 229 CG: 171	12 week bounding programme lasting 3-5 minutes in addition to normal training plus a maintenance program from week 13 - 39	Hamstring injuries	Self report

van der Horst et al, 2015 [28]	Holland	Football/ soccer	24.6	Male only	IG: 292 CG: 287	Nordic hamstring exercise - progressive 13 week protocol	Hamstring injuries	Coach
van Mechelen et al, 1993 [49]	Holland	Running	X	Male only	IG: 159 CG: 168	19 minute warm-up & 19 minute cool-down to be done alongside every run. Daily stretching routine completed throughout trial duration.	Running injuries	Self report

Table 2. PEDro Scale

Study	Eligibility criteria specified	Random allocation	Concealed allocation	Groups similar at baseline	Participant blinding	Therapist blinding	Assessor blinding	Adequate follow-up	Intention to treat analysis	Between groups comparison	Point estimates and variability	Total
Baltich et al, 2017 [41]	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	5/10
Engebresten et al, 2008 [46]	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	5/10
Espinosa et al, 2015 [13]*	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5/10
Finch et al, 2016 [10]	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	5/10
Gabbe et al, 2006 [40]	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	No	4/10
Gouttebarge et al, 2020 [11]	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	5/10
Hammes et al, 2015 [8]	Yes	Yes	No	No	No	No	No	Yes	No	Yes	Yes	4/10
Holmich et al, 2010 [25]	No	Yes	Yes	No	No	No	No	No	No	No	No	2/10
Jamtvedt et al, 2010 [21]	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	6/10
Mohammodi 2007 [47]	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5/10
Sodermann et al, 2000 [48]	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	4/10
Taddei et al, 2020 [5]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	8/10
van Beijsterveldt et al, 2012 [26]	Yes	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	5/10
van de Hoef et al, 2019 [27]	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	4/10
van der Horst et al, 2015 [28]	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	5/10
van Mechelen et al, 1993 [49]	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	4/10

***no PEDro database information available for this study**

Table 3 - Summary of findings and quality of evidence (GRADE)

	Quality Assessment					Participants, n		Effect	
Meta-analysis	**Risk of bias**	**Inconsistency**	**Indirectness**	**Imprecision**	**Publication Bias**	**IG**	**CG**	**IRR/IHR (95% CI)**	**GRADE Quality**
Exercise-based prevention programmes reporting RR	○	○	○	○	⊗	2,142	2,290	0.94 (0.80, 1.09)	⊗○○○○ *Very low*
Exercise-based prevention programmes reporting HR	○	○	○	○		2,102	1,968	0.65 (0.39, 1.08)	○○○○ *Very low*

Supplementary Material 1 – Online Search Strategy

#	Query	Limiters/Expanders
S4	S1 AND S2 AND S3	Search modes - Boolean/Phrase
S3	injur*	Search modes - Boolean/Phrase
S2	prevent* and intervent*	Search modes - Boolean/Phrase
S1	athlet* or player* or sport*	Search modes - Boolean/Phrase

The search strategy was used for all eleven data sources. The search was not restricted to any publication date.