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Evaluating The Effectiveness Of Diverse Preventive Strategies For Sports Injuries: A Systematic Review Of Randomized Controlled Trials

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Abstract

Introduction: Sports have important implications for population health. Therefore, it is challenging to reduce and prevent these injuries. This systematic review aims to assess, update, and summarize studies discussing the different prevention strategies for sports injuries and highlighting their effects and implications for different populations. **Methods:** A systematic search identified randomized controlled trials (RCTs) published up to June 2024 using PubMed, Medline, OVID, Scopus, and Cochrane Central Register of Controlled Trials. Inclusion criteria were studies examining the effects of preventive interventions on sports injuries among adolescents and adults. Thirteen studies met the criteria, covering interventions such as neuromuscular training (NMT), balance programs, FIFA 11+, lace-up ankle braces, perturbation training, laser therapy, mindfulness, and fascial manipulation. **Results:** The interventions demonstrated varying levels of effectiveness. NMT programs reduced lower extremity injuries, including a 32% reduction in non-contact injuries (95% CI: 0.51-0.93). Lace-up ankle braces halved the risk of ankle sprains (HR=0.39, 95% CI: 0.24-0.65, p<0.001). Mindfulness programs reduced injury incidence from 1.86 ± 2.23 injuries per participant (p=0.0005). Multistation proprioceptive programs lowered ankle injury risk by 35%, while balance programs reduced ankle sprain rates by 50% (p=0.04). Despite the variability in effectiveness, tailored interventions based on sport, gender, and age showed the highest impact. **Conclusion**: Preventive strategies effectively reduce injury rates and improve performance, particularly when interventions are tailored. NMT programs, ankle braces, and mindfulness training stand out as impactful. To optimize outcomes, sports organizations should mandate structured warm-up and prevention protocols. Policymakers should implement guidelines ensuring adherence, supported by coach education and regular audits. Future research should investigate long-term adherence, gender-specific effects, and intervention scalability, especially in lower-resource settings.

Keywords: sports injury, interventions, prevention strategies, injury rate, randomized controlled trials

Introduction

Sports has important implications for population health. Nevertheless, adults and adolescents face significant health burdens owing to injuries associated with sports, increasing injury rates, and their long-term consequences. The prevalence of sports injuries varies based on demographic factors, affecting various aspects of life, including the physical, psychological, social, and professional domains (1). Consequently, reducing and preventing these injuries is a significant challenge (2). The prevalence and impact of these highlights the need for targeted and inclusive prevention strategies. Many risk factors contribute to sports injury. These include intrinsic risk factors, such as age, previous injury, gender, and body weight, as well as physical and psychological factors, such as muscle flexibility and strength, emotional stress, anxiety, and depression; extrinsic risk factors, including environmental conditions, training volume, load, intensity, and type of training; inadequate coaching, (3) and competitive sports events that heighten the risk of injuries. These interdependent factors necessitate a multidimensional approach to prevention strategies, integrating insights from both risk assessment and sports injury patterns (4) .There are different types of sports injury interventions. A recent systematic review and meta-analysis identified 20 interventions used across 155 studies. The included studies revealed that behavioral change is among most interventions (55%). These may include activities and neuromuscular exercise interventions. In addition, the number of studies highlighting the role of training programs targeting the pre-event phase and equipment to avoid injury in the event phase was 73 and 29, respectively (5).

According to McBain K et al., interventions designed to prevent sports injuries in the literature primarily examined equipment or training interventions focusing more on contact sports than on non-contact sports. However, only 4% studied the rules and regulations that govern sports.[1] In 2014, Leppänen M et al. conducted a systematic review and meta-analysis of randomized controlled trials (RCTs) on sports injury preventive interventions. Their analysis revealed specific outcomes regarding the effect of certain interventions, showing several drawbacks of the included research, such as article heterogeneity, quality of trials, and overall generalization issues (6). Over the past few decades, research on sports injuries has increased. More than 1000 papers were published between 2015 and 2024. The effect of preventive interventions on sports injuries was emphasized in several RCTs, ranging from traditional approaches in the past to modern and interdisciplinary approaches (7). Although several systematic reviews have discussed the effects of specific interventions on populations, research on comprehensive intervention strategies remains limited and requires updates. Therefore, this systematic review aims to assess and update the current knowledge, summarizing studies that discuss different prevention strategies for sports injuries and highlighting their effects and implications for various populations.

The novelty of this study lies in its integrative approach, which emphasizes the comparative efficacy of traditional and contemporary interventions across various populations. By synthesizing the findings from 13 rigorously selected RCTs, this review offers actionable insights for policymakers, coaches, and healthcare professionals. Our findings aim to not only enhance athlete safety, but also inform the development of sustainable sports programs that prioritize injury prevention. This study serves as a critical step towards refining current practices and fostering innovation in sports medicine.

Methods

Study Design

The present systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and reproducibility. The review process includes four key steps: identification, screening, eligibility, and inclusion. Each step was documented and rigorously followed to align with the PRISMA standards, ensuring that all the included studies met the predefined criteria. This process is illustrated in Figure 1.

Search strategy

A systematic computerized search was performed to select relevant papers published until June 2024 using five electronic databases: PubMed, Medline, OVID, Scopus, and Cochrane Central Register of Controlled Trials. The search terms used were a combination of database-specific terms MesH terms. The search strategy was as follows:

(("intervention s"[All Fields] OR "interventions"[All Fields] OR "interventive"[All Fields] OR "methods"[MeSH Terms] OR "methods"[All Fields] OR "intervention"[All Fields] OR "interventional"[All Fields] OR ("therapeutics"[MeSH Terms] OR "therapeutics"[All Fields] OR "therapies"[All Fields] OR "therapy"[MeSH Subheading] OR "therapy"[All Fields] OR "therapy s"[All Fields] OR "therapys"[All Fields]) OR ("prevent"[All Fields] OR "preventability"[All Fields] OR "preventable"[All Fields] OR "preventative"[All Fields] OR "preventatively"[All Fields] OR "preventatives"[All Fields] OR "prevented"[All Fields] OR "preventing"[All Fields] OR "prevention and control"[MeSH Subheading] OR ("prevention"[All Fields] AND "control"[All Fields]) OR "prevention and control"[All Fields] OR "prevention"[All Fields] OR "prevention s"[All Fields] OR "preventions"[All Fields] OR "preventive"[All Fields] OR "preventively"[All Fields] OR "preventives"[All Fields] OR "prevents"[All Fields])) AND ("athletic injuries"[MeSH Terms] OR ("athletic"[All Fields] AND "injuries"[All Fields]) OR "athletic injuries"[All Fields] OR ("sports"[All Fields] AND "injuries"[All Fields]) OR "sports injuries"[All Fields] OR (("sport s"[All Fields] OR "sports"[MeSH Terms] OR "sports"[All Fields] OR "sport"[All Fields] OR "sporting"[All Fields]) AND ("injurie"[All Fields] OR "injuried"[All Fields] OR "injuries"[MeSH Subheading] OR "injuries"[All Fields] OR "wounds and injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "wounds and injuries"[All Fields] OR "injurious"[All Fields] OR "injury s"[All Fields] OR "injuryed"[All Fields] OR "injurys"[All Fields] OR "injury"[All Fields])))) AND

((randomizedcontrolledtrial[Filter]) AND (1986:2024[pdat]))

Inclusion Criteria

Studies were considered for inclusion if they met all of the following criteria: (a) studies evaluated the effect of a preventive intervention on the occurrence of sports injuries among adolescents and/or adults; (b) both (male and female) were healthy and physically active when they experienced the injury; (c) studies that targeted all injuries or injuries in specific body regions; (d) the study design was an RCT; (e) the study results contained a quantitative injury measure as an outcome; and (f) studies published between 1986 and 2024.

Exclusion Criteria

The exclusion criteria were as follows: (a) studies with no full-access link; (b) studies in languages other than English; (c) study types such as case reports, letters, observational studies, review articles, and systematic review articles; (c) duplicate studies found in multiple databases or sources; and (d) injury prevention studies assessing interventions conducted outside typical sports settings, such as military training studies.

Study Selection

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA). Before initiating the screening process, duplicate studies were removed. All the identified studies underwent a two-step screening process to determine their relevance. Initially, all the studies were evaluated for inclusion based on their titles and abstracts. Full-text articles were retrieved in case of uncertainty. Two reviewers conducted a preliminary screening phase to ensure familiarity with the inclusion criteria. Subsequently, two authors independently screened the full-text articles to make the final inclusion decisions. A third author was contacted to resolve any conflict during the screening process. Finally, the eligibility of the selected studies was assessed.

Data Extraction

Two independent authors extracted data from the included studies by using an Excel spreadsheet. These data included demographics, such as title, author, study aim, design, participant characteristics, sports injury preventive intervention, and study outcomes. The primary aim of each sports injury prevention study was to organize the extracted data. The extracted data were categorized by thorough consistency checks to ensure accuracy and reliability. Moreover, to mitigate potential biases, several measures were implemented: reviewers were blinded during the data extraction and quality assessment phases, a standardized template was used to ensure uniformity in data collection, strict adherence to pre-established inclusion and exclusion criteria minimized selection bias, and cross-checking of the extracted data was conducted to detect and correct inconsistencies.

Risk of Bias Assessment

The risk of bias in the included studies was assessed using the Cochrane Risk of Bias tool in Review Manager 5.4 by the Cochrane Collaboration. This tool evaluates the methodological quality of studies across several domains including random sequence generation, allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias), and other potential sources of bias. The assessment was conducted by reviewing the study's methodology and results sections, and data were organized using statistical software, such as Excel, to document the findings systematically. Each domain was critically reviewed and assigned a risk level (low, high, or unclear), based on the study's reported procedures and transparency in addressing potential biases(8). The risk of bias assessment is visualized in **Figure 1 & Figure 2.**

Figure 1. Traffic Light" Plot of Risk of Bias of Included Studies

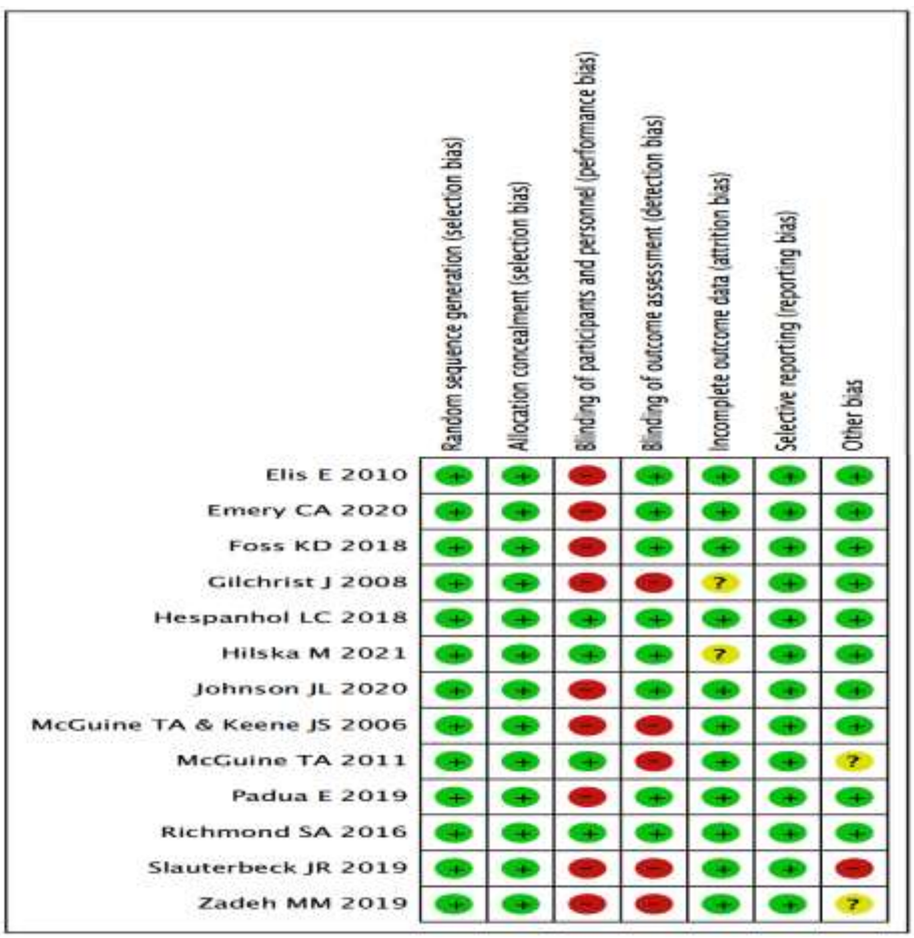
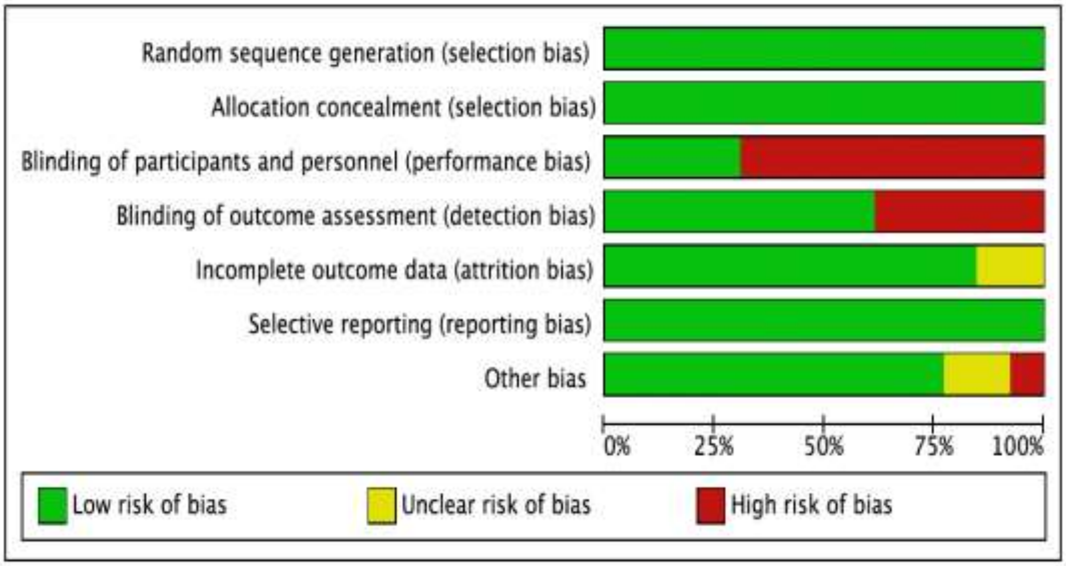


Figure 2. “Weighted Plot" Distribution of Risk of Bias Among the Studies



3. Results

Study Characteristics

The systematic search initially identified 2,190 articles from five databases: PubMed (791), SCOPUS (660), Medline (579), Ovid (21), and Cochrane Central (139). To ensure data consistency and eliminate redundancy, 296 duplicate records were removed during the preliminary stage, leaving 1,894 unique articles for screening. The title and abstract screening of these 1,894 records led to the exclusion of 1,804 articles based on predefined eligibility criteria. The exclusions comprised 583 chapters, 245 reviews, 15 books, 16 editorials, and 946 non-randomized controlled trials (non-RCTs). This rigorous screening process reduced the number of studies eligible for detailed evaluation to 90 articles, which were subsequently subjected to full-text review. The full-text screening phase further refined the selection, excluding 50 studies for various reasons. Of these, 22 studies were excluded due to irrelevant outcomes that did not align with the review objectives. Additionally, three studies were excluded due to inappropriate study designs that failed to meet the methodological inclusion criteria, while two studies were excluded due to limited data availability, which precluded a comprehensive analysis. Following this comprehensive multi-stage screening process, 13 studies were deemed to meet the predetermined inclusion criteria and were included in the final systematic review. These studies represented the most relevant and high-quality evidence available within the scope of this review. The detailed selection process is visually represented in the PRISMA flow diagram **Figure 3 (9),** which provides a clear and concise overview of each stage of the study selection. This systematic and meticulous approach ensures that the included studies accurately reflect the objectives of the review while maintaining methodological rigor. Complete characteristics of each study are mentioned in the study characteristics table, **Table 1.**

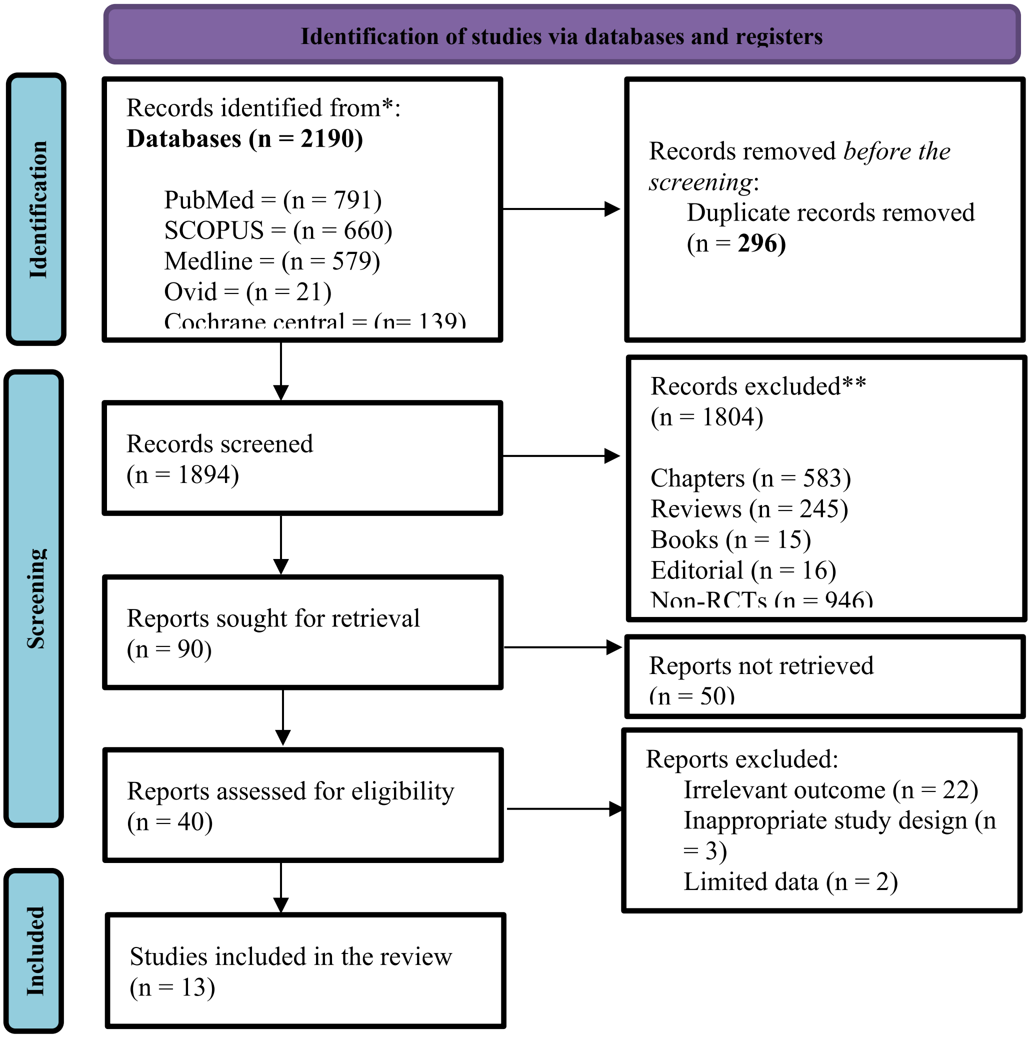


Figure 1. PRISMA flow chart

Table 1. Study Characteristics

Author (Study ID)	**Study Design**	**Study Aim**	**Study Interventions Study Control (N)/ Regimen**	**Study Population Characteristics**	**Injury Type**	**Study Outcomes**
Johnson JL et al., 2020 (10)	RCT Single blinded	To determine whether adding perturbation training to a second injury prevention program was more effective than the prevention program in reducing second anterior cruciate ligament (ACL) injury rates in female athletes after ACLR.	**Interventions:** Progressive strengthening, agility, plyometric, and prevention (SAPP) or SAPP plus perturbation training (SAPP+PERT) groups each had ten sessions over five weeks. Occurrence and side of the second ACL injury were recorded for two years after primary ACLR. Those who intended to return to cutting/pivoting sports were enrolled 3-9 months after primary ACLR.	**Female N** = 39 - SAPP (n=20) - SAPP+PERT (n=19) **Age** SAPP = 18.9 ± 5.8 SAPP+PERT = 19.0 ± 8.8	Anterior cruciate ligament (ACL) injuries	There were **nine second ACL injuries** in the two years after ACLR. There was **no statistically significant** difference in the rate or side of second ACL injury between the SAPP+PERT and SAPP groups.
Hilska M et al, 2021 (11)	RCT Clustered	To investigate whether NMT warm-up operated by team coaches effectively prevents acute lower extremity (LE) injuries in	**Intervention:** Coaches were introduced to NMT warm-up to replace the standard warm-up 2 to 3 times per week (20 minutes each). **Control:** were asked to continue their	N = 1403 players - Intervention n = 673 - Control n = 730 **Age** range: 9-14 years Intervention: 12.2 ± 1.2	**Lower extremity (LE) injuries**	**Number of injuries** Six hundred fifty-six acute LE injuries occurred: 310 in the intervention group and 346 in the control

		competitive U11-U14 soccer players.	usual warm-up routines during the study Teams were assessed for 20 weeks. The NMT warm-up consisted of 7 different exercises with progression and variations of diverse difficulty focusing on the players' motor skills and movement quality. Period.	Control: 12.3 ± 1.1 **Gender:** Female = 280 Intervention: 117 Control: 163 Male = 1123 Intervention: 556 Control: 567		group. **The overall acute LE injury incidence** - 4.4 per 1000 hours of exposure in the intervention group - 5.5 per 1000 hours of exposure in the control group (no significant difference between groups (incidence rate ratio [IRR], 0.82 [95% CI, 0.64-1.04]). **There were 302 acute non-contact LE injuries:** - 129 in the intervention group (incidence, 1.8 per 1000 hours) - 173 in the control group

						(2.7 per 1000 hours). **A significant % reduction in acute non-contact LE** injuries of 32% (IRR, 0.68 [95% CI, 0.51-0.93]) was observed in the intervention group compared with the control group. **Significant reductions in injury incidence in favor** of the intervention group were seen in the subanalyses of acute non-contact LE injuries, leading to ≤7 days of time loss and fewer ankle and joint/ligament injuries.
Emery CA et al., 2020 (12)	RCT Clustered	To evaluate the effectiveness of a PE curriculum-based NMT program in	**Intervention:** Following the iSPRINT program, which is a 15-minute NMT warm-up including aerobic,	**N =** 1067 - Control n = 501 - Intervention n = 566	Different types (of Lower extremity injuries and Medically	The **iSPRINT program** was protective of all recorded

		reducing the rate of each Sport and Recreation (S&R) medical attention and Knee and ankle injuries in girls and boys in junior high school.	agility, strength, and balance exercises. **Control:** Warm-up was a standard-of-practice program that included aerobic, static, and dynamic stretching exercises.	**Age:** Control = 13 (11–16) Intervention = 13 (11–16) **Gender:** Female: 53.7% Control = 292 Intervention = 281 Male: 46.3% Control = 209 Intervention = 285	treated injuries)	sport and recreation (S&R) injuries for girls **(IRR=0.543, 95% CI 0.295 to 0.998)** but not for boys (IRR=0.866, 95% CI 0.425 to 1.766). **The iSPRINT program was also protective of each of lower extremity injuries (IRR=0.357, 95% CI 0.159 to 0.799)** and medical attention injuries (IRR=0.289, 95% CI 0.135 to 0.619) for girls, but not for boys (IRR=1.055, 95% CI 0.404 to 2.753 and IRR=0.639, 95% CI 0.266 to 1.532, respectively).

Padua E et al., 2019	RCT	To investigate the effects of general and combined warm-up on ankle injury range of motion (ROM) and balance in young female basketball players.	**Intervention:** A combined warm-up experimental group (CWU) Performed a single-leg stance barefoot with eyes closed, plank forearm position, and triceps sural stretching. **Control:** A Global warm-up control group (GWU) Performed walking ball handling and core stability using a Swiss ball. All participants performed 7-min of a run. Both groups' routines were conducted three times per week for ten weeks.	**Female N =** 28 - Control n = 11 - Intervention n = 17 **Age** = 14.88 ± 1.48 Control = 15.44 ± 1.94 Intervention = 14.59 ± 1.12	Ankle injury	Participants in the experimental group improved significantly in the range of motion (ROM) in the right and left ankle ($p < 0.05$ and the center of pressure displacement (CoP) ($p < 0.05$). The control group showed no changes in ankle dorsiflexion and a significant reduction in all body balance parameters.
Slauterbeck JR et al, 2019 (13)	RCT clustered	To test whether high schools in which coaches implement the FIFA 11+ injury prevention program in their athletic programs will have a decreased incidence of lower extremity injuries compared	**Intervention:** FIFA 11+ injury prevention program **Control :** Usual warm-up routine.	**N =** 3611 - Control n = 1786 - Intervention n = 1825 **Age:** not mentioned **Gender: Female: Male ratio** Control = 1.33: 1.56 Intervention = 1.69: 1.50	Lower extremity injuries	There were **196** lower extremity injuries among the FIFA 11+ group and **172 injuries** among the control group (**1.59 and 1.47 injuries per 1000 athletes exposure (AEs), (respective**

		with schools using their usual prepractice warm-up.				**ly; p =0.771)** The FIFA 11+ group had larger thigh and foot injuries, while the control group had higher Knee and ankle injuries. Group differences in injury rates varied with sport (p = 0.041 for interaction). In the FIFA 11+ group **= 62%** of the coaches reported that their teams completed the full FIFA 11+ program at least once a week, and 32% reported completing it at least twice a week.
Zadeh MM et al, 2019 (14)	RCT a paralle l-group, pre-	To examine whether greater mindfulness scores were associated	**Intervention:** Seven-session mindfulness program based on the MAC approach	**Male N =** 45 - Control groups n = 22 - Interventio n n = 23	**NA**	Significantl y greater mindfulnes s scores in the interventio

	and post-test	with reduced injury rates in soccer players and improved individual and team performance.	**Control:** Received usual coaching	**Age** Control = 23.77 (1.95) Intervention = 24.86 (4.68)		n group were associated with reduced injury and improved performance. The mean number of injuries in the pre-test experimental group = 1.86 (±2.23) The mean number of injuries in post-test experimental group = 0.45 (± 0.86) (p = 0.0005)
Foss KD et al., 2018 (15)	RCT clustered	To determine the effects of a school-based NMT program on sport-related injury incidence across three sports at the high school and middle school levels, focusing particularly on knee and ankle injuries	**CORE Intervention:** Exercises focused on the trunk and lower extremities. **SHAM protocol:** Resisted running using elastic bands. Each intervention was implemented at the start of the season and continued until the last competition. An athletic trainer evaluated athletes weekly for sport-related injuries.	**Female (N) =** 474 basketball, soccer, and volleyball - CORE n = 259 - SHAM n = 215 **Age** = 14.0 ± 1.7 years	knee and ankle injuries	The CORE group reported 107 injuries **(rate = 5.34 injuries/1000 AEs)** **The** SHAM group reported 134 injuries **(rate = 8.54 injuries/1000 AEs; F1,578 = 18.65, p < 0.001).** - Basketball (rate = 4.99 injuries

						/1000 AEs) - volleyball (rate = 5.74 injuries /1000 AEs) - Athletes in the CORE group demonstrated lower injury incidences than basketball **(rate = 7.72 injuries/1000 AEs)** and volleyball **(rate = 11.63 injuries/1000 AEs; F1,275 = 9.46, p = 0.002 and F1,149 = 11.36, p = 0.001, respectively)** athletes in the SHAM group.

						- The CORE intervention appeared to have a greater protective effect on knee injuries at the middle school level **(knee-injury incidence rate = 4.16 injuries/1000 AEs)** than the SHAM intervention **(knee-injury incidence rate = 7.04 injuries/1000 AEs; F1,261 = 5.36, p = 0.02).** No differences between groups for ankle injuries **(F1,578 = 1.02, p = 0.31**).

Hespanhol LC et al, 2018 (16)	RCT Two arm	To evaluate the effectiveness of adding online tailored advice (TrailS6) to general advice on (1) the determinants and actual preventive behavior and (2) the prevention of running-related injuries (RRIs) in Dutch trail runners	**Intervention:** Participants received online general advice on RRI prevention one week after baseline. Every two weeks, participants received specific advice tailored to their RRI status. **Control:** Participants received online general advice on RRI prevention one week after baseline. Then received no further intervention.	**N =** 232 - Control n = 117 - Intervention n = 115 **Age** mean (SD) Control = 44.8 (9.3) Intervention = 44.3 (9.8) **Gender:** Female: Interevntion = 31.3 (36) Control = 33.3 (39) Male: Intervention = 68.7 (79) Control = 66.7 (78)	Running related injuries (RRIs)	Trail runners in the intervention group sustained **13% fewer RRIs than those in the control group after six months of follow-up** (absolute risk difference −13.1%, 95% Bayesian highest posterior credible interval (95% BCI) −23.3 to −3.1). A preventive benefit was observed in **one** out of eight trail runners who had received the online tailored advice for six months (number needed to treat 8, 95% BCI 3 to 22). No significant between-group difference

						was observed in the determinants and actual preventive behaviors.
Richmond SA et al, 2016 (17)	RCT clustered	To examine a school-based high-intensity NMT program that reduces sports injury risk and improves fitness in youth.	**Intervention:** A 12-week high-intensity NMT program (including aerobic, strength, balance, and agility components) **Control:** Standard of practice warm-up (including running and stretching).	Students n = 725 - Control n = 372 - Intervention n = 353 Age = 11-15 Control = 13 (IQR: 12-13) Intervention = 13 (IQR: 12-14) **Gender:** Female: Control: 57.0 (52.0-62.0) Intervention: 57.2 (52.0-62.4) Male: Control: 43.0 (38.0-48.0) Intervention: 42.8 (37.6-57.2)	Lower extremity, ankle, and knee sprain injury	**Reduced risk of sports injury:** - Incidence rate ratio (IRR) of all injuries = 0.30 (95% CI, 0.19-0.49) - IRR lower extremity injury = 0.31 (95% CI, 0.19-0.51) - IRR ankle sprain injury = 0.27 (95% CI, 0.15-0.50) IRR knee sprain injury = 0.36 (95% CI, 0.13-0.98).
McGuine TA et al,2011(18)	RCT clustered	To determine whether lace-up ankle braces (1)	**Intervention:** Wearing lace-up ankle braces	**N** = 1460 - Control n = 720	**Acute ankle, Knee, and**	**The rate of acute ankle injury** (per

		reduce the number and severity of acute first-time and recurrent ankle injuries sustained by high school basketball players and (2) affect the incidence of other lower extremity injuries.	during the 2010 football season. **Control:** No ankle braces were provided Athletic trainers recorded brace compliance, athletic exposures, and injuries.	- Interventio n n = 740 **Age:** Control = 16.0 ± 1.1 Intervention = 16.0 ± 1.1 **Gender:** Female: Control = 380 (52.8) Intervention = 356 (48.2) Male: Control = 340 (47.2) Intervention = 384 (51.8)	**lower extremity injuries**	1,000 exposures) was **0.48** in the braced group compared to 1.12 in the control group (Cox Hazard Ratio (HR)=0.39, 95% CI, 0.24, 0.65, p < 0.001). The severity (median days lost) of acute ankle injuries was the same (5 days) in both groups (p = 0.985). **The rate of acute knee injury** - 0.70 in the braced group - 0.69 in the control group (HR=0.92 [0.57, 1.47], p = 0.721). There was no difference (p = 0.242) in the severity of knee injuries between the groups

						(controls = 11.5 days, braced =17 days. **The rate of other lower extremity injuries** - 0.95 in the braced group - 1.32 in the control group (HR=0.72 [0.48, 1.09], p = 0.117) while the severity was similar in both groups (6 days versus seven days, p = 0.295).
Eils E et al., 2010 (19)	RCT	To investigate the effectiveness of a multistation proprioceptive exercise program for preventing ankle injuries in basketball players using a prospective randomized controlled trial in combination with biomechanical tests of neuromuscul	**Intervention:** Training group performing a multistation proprioceptive exercise program. **Control:** With normal workout routines The exercise period took 20 min (including setup and removal). The exercises were performed for 45 seconds, followed by a 30-s break when subjects	**N** = 172 - Control n = 91 - Intervention n = 81 **Age:** Control = 25.5 ± 7.2 Intervention = 22.6 ± 6.3 **Gender:** Female Control = 37 Intervention = 32 Male: Control = 54 Intervention = 49	Ankle injuries	**Number of injuries** In the control group, 21 injuries occurred, whereas in the training group, seven injuries occurred. The risk of sustaining an ankle injury was significantly reduced in the training group by

		ar performance.	transferred to the next station.			approximately **35%.** The corresponding number needed to treat was 7. Analysis of players who had previously sustained an ankle injury revealed an odds ratio of 1.6 (95% CI = 0.755-3.553, p = 0.212), indicating an increased but non-significant risk (factor = 1.6) of sustaining an ankle injury.
Gilchrist J et al, 2008 (20)	RCT Clustered	To test whether a simple on-field alternative warm-up program can reduce non-contact Anterior Cruciate Ligament (ACL) injuries.	**Intervention:** Teams received a videotape and instruction manual for the alternative warm-up and were asked to complete the warm-up three times per week during the fall 2002 season. **Control:** Teams were asked to perform their customary warm-up; they received all intervention materials after	**Female (N)** = 1435 - Control n = 852 - Intervention n = 583 **Age:** Control = 19.88 Intervention = 19.88	Anterior Cruciate Ligament (ACL) injuries	The overall ACL **injury rate** among intervention athletes was 1.7 times less than in control athletes (**0.199 vs 0.340;** p = **0.198; 41 % decrease).** - The non-contact ACL

			completing all data collection at the end of the season.				injury rate among intervention athletes was 3.3 times less than in control athletes **(0.057 vs 0.189; p = .066; 70% decrease).** - No anterior cruciate ligament injuries occurred among intervention athletes during practice versus six among control athletes (p = **0.014).** - Game-related non-contact anterior cruciate ligament injury rates in

						intervention athletes were reduced by more than half **(0.233 vs 0.564; p = 0.218).** - Intervention athletes with a history of anterior cruciate ligament injury were significantly less likely to suffer another anterior cruciate ligament injury than control athletes with a similar history **(p = 0.046 for non-contact injuries).**

McGuine TA and Keene JS, 2006 (21)	RCT clustered	To determine whether (1) the effect of the intervention was the same for athletes with or without a history of an ankle sprain; (2) the rate of ankle sprain was affected by independent variables such as gender, sport, leg dominance, use of ankle supports and laxity; and (3) balance training reduced the severity of ankle sprains high school athletes.	**Intervention:** A balanced training program **Control:** Standard conditioning exercises group	**N =** 765 - Control n = 392 - Intervention n = 373 **Age** Control = 16.6 ± 1.1 Intervention = 16.4 ± 1.2 **Gender:** **Female** = 523 Control = 262 (66.8) Intervention = 261 (69.9) **Male** = 242 Control = 130 (33.1) intervention = 112 (30.1)	Ankle sprains	The rate of ankle sprains was significantly lower for subjects in the intervention group **(6.1%, 1.13 of 1000 exposures vs 9.9%, 1.87 of 1000 exposures; p = 0.04).** Athletes with a history of an ankle sprain had a 2-fold increased **risk of sustaining a sprain** (risk ratio, 2.14), whereas athletes who performed the intervention program decreased their risk of a sprain by one-half (risk ratio, 0.56). **The ankle sprain rate for** athletes without previous sprains = 4.3% in the interventio

						n group and 7.7% in the control group (p = 0.059).
N = number, M = Mean, SD = standard deviation, CI = Confidence interval, RCT = Randomized controlled trial, ACL = anterior cruciate ligament, SAPP = strengthening, agility, plyometric, and prevention, PERT = perturbation training, LE = lower extremity, IRR = incidence rate ratio, NMT = neuromuscular training, S&R = Sport and Recreation, FM = Fascial Manipulation, CAI = chronic ankle instability, CWU = combined warm-up, GWU = Global warm-up, ROM = range of motion, AE = athletes exposure, MAC = mindfulness, acceptance and commitment, CORE = exercises focused on the trunk and lower extremity, SHAM: resisted running with elastic bands, LLLT = Low level laser therapy, HR = Hazard ratio						

Findings

Neuromuscular training (NMT) programs

NMT programs were studied in five studies. Neuromuscular training (NMT) programs have demonstrated significant efficacy in reducing injury rates, particularly for lower-extremity injuries. For example, Hilska et al. (2021) reported a 32% reduction in non-contact lower extremity injuries among adolescent soccer players participating in NMT warm-ups (IRR: 0.68, 95% CI: 0.51-0.93). Emery et al. (2020) showed that NMT programs were particularly effective for girls, reducing sport and recreation injury incidence by 46% (IRR: 0.543, 95% CI: 0.295-0.998), though this effect was not observed in boys (IRR: 0.866, 95% CI: 0.425-1.766). Richmond et al. (2016) found that a high-intensity NMT program reduced overall injury rates by 70% (IRR: 0.30, 95% CI: 0.19-0.49). Similarly, Foss et al. (2018) noted that trunk-focused NMT exercises significantly reduced knee injury incidence rates among middle school athletes (4.16 injuries per 1,000 athlete exposures) compared with a sham protocol (7.04 injuries per 1,000 athlete exposures, p = 0.02). Gilchrist et al. (2008) demonstrated that an alternative NMT warm-up reduced non-contact ACL injury rates by 70% in female soccer players (0.057 vs. 0.189 per 1,000 athlete exposures, p = 0.066), highlighting the importance of structured programs during practice. These findings underscore the importance of gender-specific tailoring, high-intensity protocols, and consistent implementation in NMT effectiveness (11, 12, 15, 17, 20).

Balanced training programs

Balance training programs are effective in reducing ankle sprain rates. McGuine and Keene (2006) observed a significant 50% reduction in ankle sprain rates among high school athletes who performed balance exercises compared to standard conditioning programs (p = 0.04). Additionally, Eils et al. (2010) demonstrated a 35% reduction in ankle injuries in basketball players participating in multistation proprioceptive training (number needed to treat: 7). These findings suggest that balance training, especially in structured multistation formats, is a valuable preventive measure for ankle-related injuries (21).

Ankle Braces

Ankle braces are effective in preventing acute injuries, particularly sprains. McGuine et al. (2012) found that athletes wearing lace-up ankle braces during high school basketball games experienced a 61% reduction in ankle injury rates compared to unbraced players (HR: 0.39, 95% CI: 0.24-0.65). However, this intervention showed no significant effect on knee or other lower extremity injuries, highlighting its specificity for ankle protection (18).

Warm-up programs

Warm-up programs are effective in improving joint stability and reducing injury rates. Padua et al. (2019) observed significant improvements in ankle range of motion (ROM) and balance among young female basketball players who performed a combined warm-up routine compared to those who performed global warm-up exercises ($p < 0.05$) and center of pressure displacement (CoP) ($p < 0.05$). Similarly, Gilchrist et al. (2008) demonstrated that an alternative warm-up program significantly decreased ACL injury rates during gameplay, particularly in female athletes (20, 22).

FIFA 11+ Program

The FIFA 11+ program yielded mixed results in preventing lower-extremity injuries. Slauterbeck et al. (2019) reported a 62% adherence rate among coaches, with participating teams experiencing a 1.59 injury rate per 1,000 athlete exposures compared to 1.47 in the control group ($p = 0.771$). Despite these overall findings, the program showed variability in effectiveness depending on sport. For instance, the intervention was more effective in soccer players, with notable reductions in thigh and foot injuries, whereas the control group exhibited higher rates of knee and ankle injuries. Additionally, approximately 32% of the coaches implemented the program more than twice weekly, which correlated with better injury prevention outcomes. This suggests that adherence and consistent execution by trained personnel are critical for maximizing the benefits of the program. However, the lack of significant differences across some sports highlights the need for tailored approaches (13).

Perturbation and Online programs

Additional interventions, such as perturbation training, showed limited efficacy in reducing injury rates. Johnson et al. (2020) evaluated the effects of adding perturbation training to a secondary ACL injury prevention program among female athletes and found no significant difference in re-injury rates between those who participated in the perturbation training group (9 injuries in 39 participants) and those who followed standard protocols. This suggests that additional perturbation training may not provide substantial incremental benefits for ACL injury prevention. Similarly, Hespanhol et al. (2018) observed a modest 13% reduction in running-related injuries (absolute risk difference: −13.1%, 95% Bayesian credible interval: −23.3 to −3.1) through an online tailored advice program. However, this intervention did not significantly influence participants' preventive behaviors, highlighting its limited practical impact (10, 16) .

Mindfulness Interventions

Mindfulness-based interventions showed notable reductions in injury incidence, promising prevention of injury, and significantly increased performance. Zadeh et alreported a decrease in average injuries per participant from 1.86 ± 2.23 ($M \pm SD$) pre-test to 0.45 ± 0.86 ($M \pm SD$) after a seven-session mindfulness program ($p = 0.0005$). This study also highlighted improvements in individual and team performance metrics. However, the relatively small sample size ($n = 45$) limits the generalizability of these results, underscoring the need for larger trials (14).

Figure 4. Injury Reduction Reportedly Achieved in Studies (%)

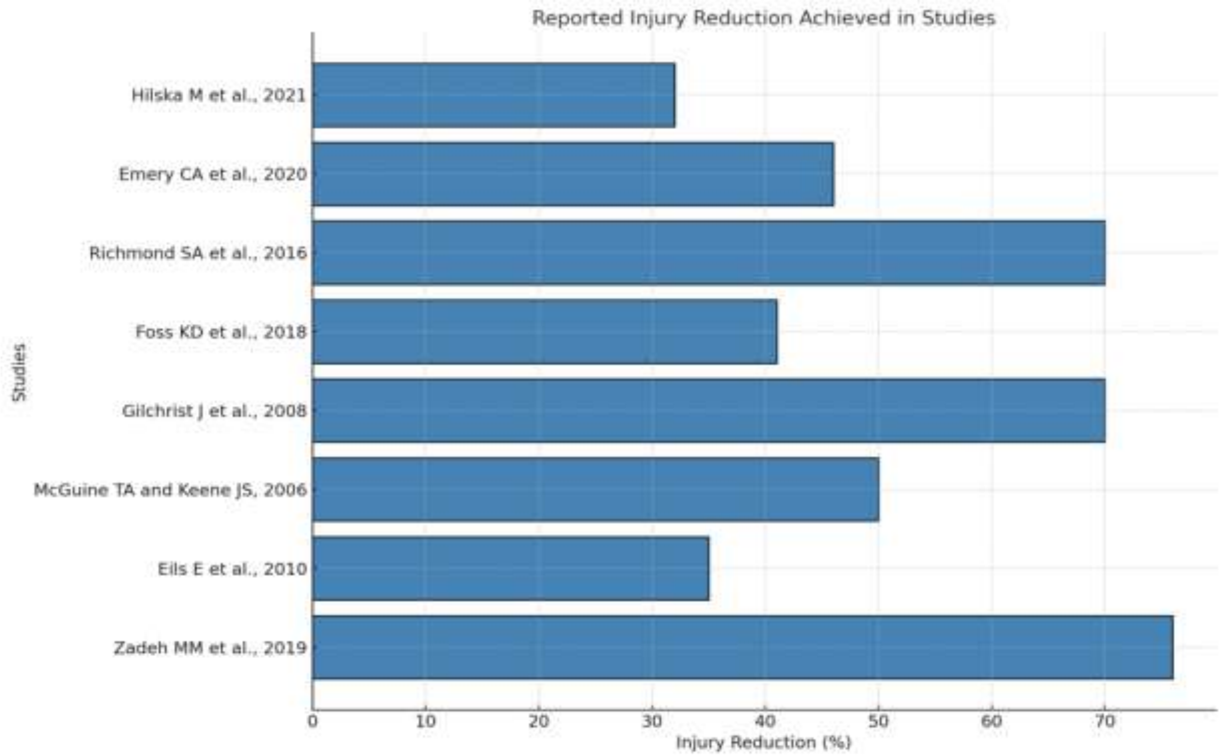


Figure 5. Injury Reduction in Percentage in Different Types of Injuries

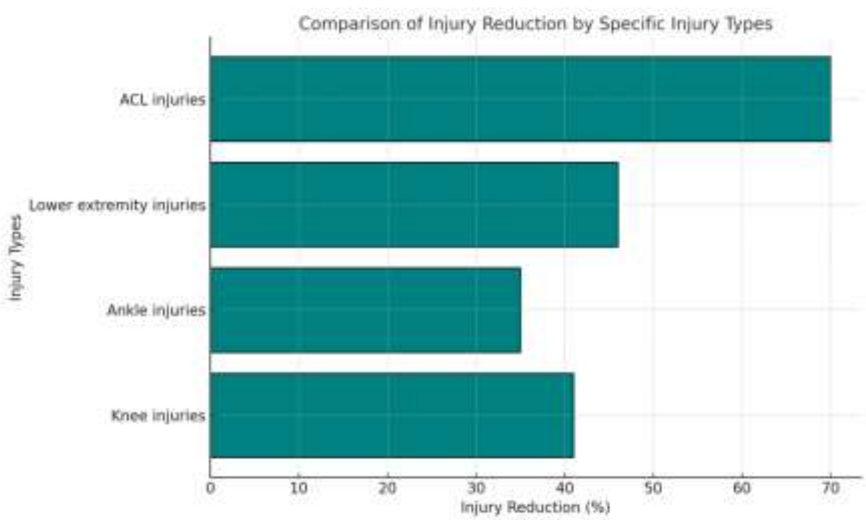
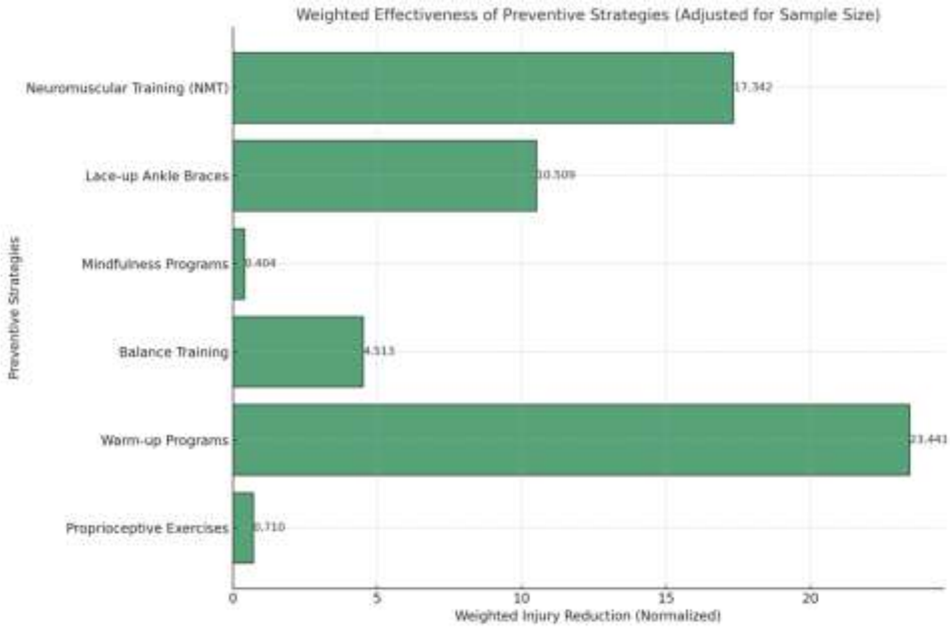


Figure 6. Weighted Effectiveness of Different Strategies



Discussion

The systematic review highlighted that diverse preventive strategies, including neuromuscular training (NMT), balance programs, mindfulness interventions, ankle braces, and structured warm-ups, demonstrate variable efficacy in reducing sports injury rates. NMT, particularly tailored to gender and sport, significantly reduced lower extremity and ACL injuries, while balance training halved ankle sprain rates. Ankle braces and mindfulness programs effectively reduced injury incidence, though the latter requires larger sample validation. The FIFA 11+ program showed inconsistent results, emphasizing adherence and expert implementation. These findings underscore the importance of individualized, context-specific strategies, combined with structured training programs and comprehensive education for optimal injury prevention and athlete safety.

Regarding NMT programs, differences in the overall acute injury incidence between the intervention and control groups were non-significant (1, 11, 20). However, significant findings were evident among specific groups, such as those who performed the CORE intervention, which consisted of exercises focused on the trunk and lower extremities in the Foss et al. study (15) . This study showed that the most significant effect was demonstrated among knee injuries in middle-school volleyball athletes. On the other hand, significant reductions were found in the alternative PEP, which affected non-contact ACL injuries in college female soccer players, particularly during practice and the second half of the season (20). Additionally, Richmond found that injury risk significantly differed among junior high PE classes (17). This may be attributed to the study design and sample differences presented, which were inconsistent in the three studies. Among the five studies, gender played a role in the efficacy of the intervention in preventing injuries. Gilchrist et al. (20) Emery et al. (1) , and Foss et al. (15) showed that the interventions had a more protective effect on female players. This was in contrast with the Hilska et al. (11) study, which did not indicate conclusive results regarding gender differences. This could be attributed to the small number of female subjects in the latter study, which was insufficient to address the significance of sex differences. However, adjustment for sex was made in the Richmond study, showing no significant differences between the two genders (17).

Considering ACL injuries, the efficacy of the NMT program was more pronounced compared to recent findings by Johnson JL et al. in 2020. Johnson JL et al (10). found that adding perturbation training to a secondary ACL injury prevention program did not affect the rate of ACL injuries in female athletes.

However, their study showed that ACL-SPORTS training significantly reduced the secondary ACL injury rates in male athletes. This finding suggests that sex differences may play a role in the effectiveness of such interventions; therefore, further research should be conducted to explore the clinical implications among both genders.

Furthermore, another included study examined the effect of lace-up ankle braces as an intervention to prevent knee injury, which observed that the intervention type, like braces types and brands, could have affected the results (18). Therefore, combining this intervention with another preventive program is recommended to improve the overall efficacy of preventing injuries in the lower extremities. Regarding warm-up programs, Padua et al (22).indicate d the efficacy of warm-up programs on injury prevention with significant values. This was confirmed by a recent systematic review conducted in 2022, which showed that warm-up programs reduced the injury rate ratio of upper and lower limb sports injuries in children and adolescents (23).

Unlike NMT programs, which have been assessed in several studies, the balance training program intervention was performed in one study in 2006. This study showed promising results regarding the beneficial effect of a balance training program as an intervention for ankle sprains (6).

Interestingly, among the included studies, only one study by Elis et al. evaluated the incidence of ankle sports injury by investigating the laboratory findings through a multistation proprioceptive exercise program (19). The study findings were significant due to the strong randomization in the sample size; however, the study results were confined to ankle injuries. Further research should be conducted to assess the efficacy of this intervention in other areas of the body.

Furthermore, the FIFA 11+ injury prevention program was the least effective sports injury preventive intervention among the included studies (13). This approach might have been more effective if it had been conducted by professional experts rather than by coaches, who may have contributed to its reduced efficacy.

The mindfulness intervention was also significantly effective in reducing sports injuries among the participants. However, the findings were inconclusive owing to the small sample size. Therefore, larger samples are required to improve generalizability and reinforce the findings.

Furthermore, the findings from the online intervention suggest that it could be beneficial as an additional approach to other interventions to increase the RRI prevention efficacy. However, it did not influence subjects' behaviors that could be associated with preventing RRIs (16).

Based on our findings, sports training programs, especially those in schools and amateur sports clubs, should incorporate a minimum of three weekly sessions of neuromuscular training to effectively reduce injury rates. These sessions should be designed to exceed 30 minutes to maximize benefits. Coaches and trainers must receive proper training to implement these programs and ensure correct and consistent execution. Moreover, considering the significant interaction effects between gender and intervention type, it is advisable to tailor training programs to address the specific needs of male and female athletes. In particular, female athletes demonstrated greater benefits from NMT programs, suggesting that gender-specific modifications to training protocols may enhance their effectiveness.

Limitations

This systematic review has a number of limitations even though it offers robust evidence regarding the efficacy of different intervention techniques. The findings may not be as broadly applicable as they may be due to the included studies' variable characteristics, intervention modalities, and outcome measures. To validate these findings in more homogeneous populations and further research is required. The fact that some studies rely on self-reported adherence to training programs, which may create bias, is another limitation. For more precise statistics, future studies should employ objective adherence metrics, including wearable technologies to monitor training session participation. Lastly, the findings may not be as applicable in settings with fewer resources because the majority of the included studies were carried out in high-income nations. More diverse populations should be included in future studies to guarantee that the results are applicable worldwide.

Future Implications

Future studies need to assess the long-term adherence to and sustained impacts of injury prevention programs in different types of sports. Examine dropout rates and reasons for discontinuation so as to assess barriers and promote retention. Long-term evaluations are needed to confirm whether the short-term gains seen in pilots will carry forward over several seasons or years. This warrants further investigation to elucidate how various forms of training conditions intercede with injury risk factors. For instance, biomechanical studies may offer novel insights into the mechanisms underlying proprioceptive and neuromuscular training (NMT) programs and their positive effects on joint stability, muscle coordination, and, ultimately, injury prevention. Research is also needed which attends to the psychosocial aspects of injury prevention. In particular, being aware of the motivating factors and barriers for athletes when adhering to these programs can help in the formulation of interventions that are not only effective but are also engaging and sustainable. Exploring variables like coaching styles, team dynamics, and peer support has the potential to provide useful information for optimizing program success. As structured warm-up programs have been proven to reduce injury rates, sports governing bodies should ensure that these programs are integrated into training and pre-game at all levels of play, from youth to adult leagues. Such policies should be created to facilitate consistent implementation and monitoring of these programs, including possible mandating of coach certification in injury prevention techniques and routine review of their training practices. Moreover, sports organizations must invest in extensive educational campaigns to promote awareness regarding the benefits of injury prevention strategies. Such efforts may demonstrate the importance of community-driven evidence for these initiatives and what practical steps athletes, coaches, and stakeholders can take to implement effective training programs.

Conclusion

This review demonstrates that the effectiveness of the most sports injury prevention strategies, especially neuromuscular and proprioceptive training, can decrease injury rates and enhance performance. However, individualized and organized interventions that are administered at scale (e.g., warm-up protocols, mindfulness programs, ankle braces) show a substantial positive association when consistantly administered. Through the implementation of these evidence-based measures, sports entities can promote athlete safety and their resilience in various populations or within sports environments. The outcome of this systematic review will help provide the body of the literature with updates on the effectiveness of sports injury preventive interventions and possibly assist physiotherapists and physicians in implementing evidence-based practices and developing targeted preventive programs.

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Consent

As this was a systematic, no consent was required.

Ethical approval

The Institutional Review Board approval is not required as this was a systematic review.

Declaration of patient consent

Patient’s consent was not required as there are no patients in this study.

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