QUALITY IN SPORT
eISSN 2450-3118 · Open Access · Peer-reviewed
apcz.umk.pl/QS Nicolaus Copernicus University in Toruń

Cite as: WALCZAK, Paulina, NIEWĘGŁOWSKA, Małgorzata, BENDER, Aleksandra, WIDOMSKA, Katarzyna, BERNAD, Mateusz, KRAZIŃSKA, Oliwia, GAŁACH, Magdalena, ŁUKASZEWICZ, Jakub, DĄBROWSKI, Kacper, SZYMULEWICZ, Bartłomiej and NEJC, Wojciech. Effectiveness and Implementation of Multicomponent Neuromuscular Training Programs for Lower Extremity Injury Prevention in Adolescent Team Sport Athletes: A Systematic Review of Systematic Reviews and Meta-analyses. Quality in Sport. 2026;56:71637. https://doi.org/10.12775/QS.2026.56.71637

ARTICLE TIMELINE
Received: 08.05.2026 Revised: 20.05.2026
Accepted: 20.05.2026 Published: 23.05.2026

INDEXING & EVALUATION
MEiN points: 20 Unique ID: 201398
Disciplines: Economics & Finance; Management & Quality Sciences

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines: Economics and Finance (Social Sciences); Management and Quality Sciences (Social Sciences).

Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).

Title: Effectiveness and Implementation of Multicomponent Neuromuscular Training Programs for Lower Extremity Injury Prevention in Adolescent Team Sport Athletes: A Systematic Review of Systematic Reviews and Meta-analyses

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Abstract

Background: Adolescent athletes participating in team sports face a high risk of lower extremity injuries, particularly knee and ankle injuries and anterior cruciate ligament (ACL) ruptures. Football (soccer) and other pivoting sports cause substantial injury burdens among youth and women, resulting in serious consequences for long-term joint health and continued sport participation. [1-5] Multicomponent neuromuscular training (NMT) programs, which typically combine strength, plyometric, balance, agility, and movement-control exercises, have been identified as a key strategy for preventing sports injuries. [6-9]

Objective: To synthesise evidence from recent systematic reviews and meta-analyses regarding (1) the effectiveness of multicomponent NMT or comparable exercise-based injury prevention programs in reducing lower extremity injuries among adolescent team sport athletes, and (2) factors influencing real-world implementation and adherence.

Methods: A systematic review of systematic reviews and meta-analyses was conducted. Recent high-quality reviews that searched databases such as PubMed, Web of Science, Embase, SPORTDiscus, CINAHL, and the Cochrane Library up to 2024 were used as primary data sources. [1, 2, 6, 7, 11-18] Reviews were eligible if they (a) focused on exercise-based injury prevention programs in sport, (b) reported effects on musculoskeletal injury incidence or risk, and (c) provided subgroup data for adolescents (10–19 years) Fand/or team sport athletes. Data on program characteristics, injury outcomes, effect sizes, and implementation determinants were extracted and synthesised narratively, with quantitative results reported as incidence rate ratios (IRR) or risk ratios (RR) from the included meta-analyses.

Results: Across multiple systematic reviews and meta-analyses, multicomponent exercise-based programs consistently reduced sports injuries among adolescent team-sport athletes. A dedicated meta-analysis of 16 randomized controlled trials in adolescent team athletes (10–19 years) found a 35% reduction in total injuries (IRR 0.65, 95% CI 0.54–0.77), 33% reduction in lower extremity injuries (IRR 0.67, 95% CI 0.57–0.80), 22% reduction in knee injuries (IRR 0.78, 95% CI 0.66–0.92), and 38% reduction in ankle injuries (IRR 0.62, 95% CI 0.47–0.81). [11-15] Shorter interventions (<20 minutes per session) that integrated warm-up, plyometric, strength, agility, and balance exercises were most effective (IRR 0.55–0.59). [11-15] Subgroup analyses indicated stronger protective effects in female athletes (IRR 0.56) compared with males (IRR 0.66). [11-15] In footballers of all ages, multicomponent programs yielded an overall RR of 0.71 (95% CI 0.59–0.85) for all injuries and RRs of 0.69–0.82 for specific knee and ankle injuries. [1, 2] Youth-specific analyses in soccer reported an RR of 0.615 (95% CI 0.512–0.739) for overall injury risk, with higher adherence associated with greater effectiveness. [17, 20] In female football, multicomponent exercise programs reduced overall injuries by 27% (IRR 0.73, 95% CI 0.59–0.91), ACL injuries by 45% (IRR 0.55, 95% CI 0.32–0.92), and hamstring injuries by 60% (IRR 0.40, 95% CI 0.17–0.95). [3-5] A large FAIR (Female, Woman and Girl Athlete Injury Prevention) consensus review confirmed that neuromuscular training programs including balance, strength, agility and change-of-direction exercises, delivered at least 10 minutes twice per week, reduced lower extremity injuries in female athletes by about 19% (RR 0.81, 95% CI 0.61–1.08). [9, 10] Implementation-focused reviews highlighted players' beliefs, coaches as key facilitators, organisational support, and program characteristics as key determinants of uptake and sustained use. [18-19]

Conclusions: Multicomponent neuromuscular training programs, particularly those integrated into regular warm-ups and performed with adequate frequency and observance, substantially reduce lower extremity injury risk among adolescent team-sport athletes, with particularly strong effects observed in female players. [3-5, 11-15, 18, 19] Optimal programs are brief (<20 minutes), high-quality sessions that combine warm-up, plyometric, strength (hamstrings and core), agility, and balance training. [9-15] Effective implementation in schools and clubs requires coach education, organisational support, and attention to athletes' perceptions and motivation. [18, 19] These findings hold important

implications for physical education, youth sport coaching, and policy aimed at supporting safer sport participation.

Keywords: adolescent athletes; neuromuscular training; injury prevention; lower extremity; team sports; implementation.

1. Introduction

Participation in organised sport during adolescence confers numerous physical, psychological, and social benefits, but also carries a considerable risk of musculoskeletal injury. Lower extremity injuries, particularly those affecting the knee and ankle, are among the most common and burdensome in popular team sports such as football (soccer), basketball, handball, and volleyball. [1-5] In women's football, overall injury incidence is estimated at approximately 3.4 injuries per 1000 exposure hours, with ankle injuries being especially frequent. [3-5] Similar injury patterns are observed across youth and adult team sports, drawing attention to the need for effective and scalable prevention strategies. [6-8, 17]

The consequences of lower extremity injuries in young athletes are considerable. Many injuries result in time loss from sport, impaired performance, and early dropout from physical activity. [17, 20] In the long term, serious knee injuries such as anterior cruciate ligament (ACL) ruptures are associated with an elevated risk of early-onset osteoarthritis, pain, and functional restrictions in adulthood. [3-5] Given high participation rates, even modest reductions in injury incidence can translate into large absolute reductions in injury burden at the population level.

Over the last two decades, a broad array of sports injury prevention programs has been developed and evaluated, including warm-up protocols, neuromuscular training (NMT) interventions, balance and proprioceptive training, strength and plyometric programs, protective equipment, and rule changes. [6-8, 16] A comprehensive overview of systematic reviews demonstrated that exercise-based prevention programs are among the most extensively studied strategies, particularly for lower extremity, ACL, ankle, and hamstring injuries. [6-8] Many of these programs are multicomponent, including elements such as strength, plyometrics, balance, agility, and sport-specific movement control. [1-5, 16]

Adolescent athletes and female players are central target groups for preventive interventions. Adolescent female athletes in pivoting and cutting sports (e.g., football, handball, basketball) display especially high rates of non-contact knee injuries and ACL ruptures compared with male peers. [3-5, 9, 10] Recent meta-analyses focusing on adolescent team athletes and female football players suggest that multicomponent NMT programs can substantially reduce injury incidence in these populations. [3-5, 11-15] However, effect sizes vary across studies, adherence is often suboptimal, and implementation in community and school settings remains limited. [17-20]

A growing number of systematic reviews and meta-analyses have synthesised the effectiveness of such programs in various sports and populations, including footballers of all ages, youth soccer players, and adolescent team athletes more broadly. [1-5, 11-15, 17] Yet, there is a

need for an integrated synthesis that explicitly examines (a) the magnitude of injury risk reduction achieved by multicomponent NMT or equivalent exercise-based injury prevention programs in adolescent team sport athletes, and (b) how program characteristics and implementation factors affect their performance in real-world contexts.

Aim

The aim of this systematic review of systematic reviews and meta-analyses was twofold:

1. To summarise the evidence on the effectiveness of multicomponent neuromuscular or other exercise-based injury prevention programs in reducing lower extremity injuries among adolescent team sport athletes (10–19 years), with particular attention to sex-specific effects; and
2. To identify key program characteristics and implementation factors (e.g., adherence, coaching, organisational support) associated with successful adoption and injury reduction in youth sport settings.

2. Methods

2.1. Study design

We conducted a systematic review of systematic reviews and meta-analyses focusing on exercise-based injury prevention programs in adolescent team-sport athletes. This approach was chosen because multiple high-quality systematic reviews and meta-analyses already exist in this field, permitting efficient synthesis of the most robust and up-to-date evidence. [1-19]

2.2. Data sources and search strategy

This review relied on systematic reviews and meta-analyses that had themselves conducted comprehensive searches of major biomedical and sport science databases, including PubMed/MEDLINE, Web of Science, Embase, CINAHL, SPORTDiscus, Scopus, and the Cochrane Library. [1, 2, 6, 7, 11-19] These underlying reviews covered publications from database inception up to dates between 2019 and 2025, with several specifying search end points such as July 2024 and October 2024. [11-16, 18, 19]

The typical search strategies in these reviews combined terms associated with sport (e.g., “football”, “soccer”, “team sports”), population (e.g., “youth”, “adolescent”, “female”), injury (e.g., “sports injury”, “ACL”, “ankle sprain”, “lower extremity”), and intervention (e.g., “injury prevention program”, “neuromuscular training”, “warm-up”, “proprioceptive training”). [1-7, 11-15, 17-19]

For the present review, we identified relevant systematic reviews and meta-analyses through the available literature summarised in recent overviews of sports injury prevention strategies, youth soccer

injury prevention, football-specific prevention programs, and female athlete injury prevention. [1-19, 21, 22]

2.3. Eligibility criteria

Systematic reviews and meta-analyses were included if they met the following criteria:

- **Population:** Athletes practising organised sports, with extractable data or dedicated analyses for adolescents (10–19 years) and/or team sport athletes. [1-5, 11-15, 17-19]
- **Intervention:** Multicomponent neuromuscular or other structured exercise-based injury prevention programs implemented as warm-ups, training modules, or separate sessions. Interventions typically included at least two of the following elements: strength, plyometrics, balance/proprioception, agility, change-of-direction, and movement-control exercises. [1-5, 9-15, 17]
- **Comparison:** Usual training, standard warm-up, no structured injury prevention program, or alternative prevention strategies.
- **Outcomes:** Musculoskeletal sports injuries, with a focus on overall injuries, lower extremity injuries, and specific outcomes such as ACL injuries, ankle sprains, and hamstring or knee injuries. Outcomes were reported as incidence rates, incidence rate ratios (IRR), risk ratios (RR), or other related measures. [1-5, 9-15, 17-19]
- **Study design:** Systematic reviews and/or meta-analyses of randomised controlled trials, cluster-randomised trials, and controlled cohort or quasi-experimental studies. [6-19]

Narrative reviews without systematic methods, reviews focusing exclusively on non-exercise interventions (e.g., surgery, pharmacologic treatment), and reviews without sport-related musculoskeletal outcomes were excluded. [6-8, 16]

2.4. Study selection and data extraction

From the available literature, we selected recent systematic reviews and meta-analyses that were directly relevant to adolescent and/or team-sport populations and reported quantitatively on exercise-based injury prevention programs. Key candidates included:

- A large qualitative overview of systematic reviews on sports injury prevention. [6-8]
- A systematic review and meta-analysis of multicomponent exercise injury prevention programs in adolescent team athletes. [11-15]
- A systematic review and meta-analysis of various injury prevention programs in youth soccer players. [17, 20]
- A systematic review and meta-analysis of multicomponent exercise-based programs in footballers of all age groups. [1, 2]
- A systematic review and meta-analysis of injury prevention programs in female football players. [3-5]
- An umbrella review of injury prevention programs in male soccer players. [21, 22]

- An overview of meta-analyses examining injury prevention programs across sports and body regions. [16]
- A comprehensive FAIR consensus review on lower extremity injury prevention strategies in female, women, and girl athletes. [9, 10]
- A multi-method systematic review of sport injury prevention programs and their implementation in adolescents. [18, 19]

For each eligible review, we extracted information on: (1) population characteristics (age range, sex, sport); (2) intervention components and delivery; (3) comparator conditions; (4) injury outcomes and effect estimates (IRR or RR with 95% confidence intervals where available); (5) program duration, frequency, and session length; and (6) implementation factors such as adherence, compliance, and reported barriers or facilitators. [1-5, 9-15, 17-19]

2.5. Risk of bias and quality appraisal

The methodological quality of the underlying primary studies and the overall strength of evidence in each included review were assessed in those reviews applying standardised tools, such as the AMSTAR-2 checklist for systematic reviews, the Cochrane Risk of Bias tool for randomised trials, and the GRADE framework for rating evidence certainty. [6-17] Most reviews reported at least moderate literary search quality and formal risk-of-bias assessment, but many individual trials were rated as having unclear or high risk of bias, and several meta-analyses were graded as low or very low certainty evidence. [3-17]

Given that this is an umbrella review, we did not reassess the risk of bias at the level of individual primary studies; instead, we relied on the assessments and GRADE ratings reported in the included systematic reviews. [1-19]

2.6. Data synthesis.

We performed a descriptive synthesis of the effect estimates reported in the included meta-analyses, focusing on:

- Overall injury incidence
- Lower extremity injuries;
- Specific injuries (knee, ACL, ankle, hamstring);
- Subgroup analyses for adolescent and female athletes;
- Effects of program dose and content; and
- Implementation-related outcomes, such as adherence and surrounding factors.

Where possible, we report pooled incidence rate ratios (IRR) or risk ratios (RR) with 95% confidence intervals from the original meta-analyses. [1-5, 11-15, 17-19] No additional statistical pooling across reviews was undertaken as a result of overlapping datasets and heterogeneity in definitions, populations, and interventions.

3. Results

3.1. Overview of included evidence

The body of evidence summarised here comprises multiple systematic reviews and meta-analyses of exercise-based injury prevention programs in athletes, many of which focus specifically on team sports, youth populations, or female athletes. [1-19, 21, 22] A detailed review of sports injury prevention strategies identified 129 systematic reviews and meta-analyses on musculoskeletal injury prevention across several sports, with nearly half classified as level 1 evidence, and most performed a comprehensive literature search and risk-of-bias assessment. [6-8]

Within this broad literature, several reviews provide targeted views on adolescent team athletes and lower extremity injury prevention:

- A meta-analysis of multicomponent exercise interventions in adolescent team athletes (10–19 years). [11-15]
- A systematic review and meta-analysis of youth soccer injury prevention programs. [17, 20]
- A meta-analysis of multicomponent exercise-based prevention programs in footballers of all age groups. [3-5]
- A systematic review and meta-analysis of injury prevention programs in female football. [3-5]
- A FAIR consensus systematic review focusing on lower extremity injury prevention strategies in girls and women. [9, 10]
- A mixed-method review of adolescent sport injury prevention programs and their implementation in community settings. [18, 19]

These reviews together provide a coherent picture of the effectiveness and pragmatic challenges of NMT and related programs in adolescent team sport contexts.

3.2. Effectiveness of multicomponent programs in adolescent team athletes

The meta-analysis focusing on adolescent team athletes (10–19 years) synthesised results from 16 randomised controlled trials of multicomponent exercise-based injury prevention programs. [11-15] These programs typically combined dynamic warm-up, jumping and plyometric drills, strength exercises, agility and change-of-direction tasks, and balance training, delivered two to three times per week during team practice sessions. [11-15]

Across these trials, multicomponent programs produced substantial reductions in several injury outcomes:

Total injuries: IRR 0.65 (95% CI 0.54–0.77), corresponding to a 35% reduction in overall sports injuries. [11-15]

Lower extremity injuries: IRR 0.67 (95% CI 0.57–0.80), indicating a 33% reduction in lower extremity injuries. [11-15]

Knee injuries: IRR 0.78 (95% CI 0.66–0.92), a 22% reduction. [11-15]

Ankle injuries: IRR 0.62 (95% CI 0.47–0.81), a 38% reduction. [11-15]

Acute injuries: IRR 0.68 (95% CI 0.57–0.81), representing a 32% reduction. [11-15]

Overuse injuries: IRR 0.61 (95% CI 0.49–0.76), corresponding to a 39% reduction. [11-15]

These results show that multicomponent programs can reduce both acute and overuse injuries across multiple body regions, with particularly strong effects on ankle and overuse injuries. [11-15]

Importantly, subgroup analyses in this adolescent meta-analysis showed that interventions lasting less than 20 minutes per session were more effective than longer sessions (≥20 minutes). [11-15] Programs shorter than 20 minutes were associated with an IRR of 0.59 (95% CI 0.44–0.79), whereas longer sessions achieved a more modest effect (IRR 0.70, 95% CI 0.57–0.86). [11-15] The most effective programs were those that combined warm-up activities with jumping/plyometrics, strength, agility, and balance training (IRR 0.55, 95% CI 0.41–0.73). [11-15] These data suggest that brief, well-structured multicomponent sessions embedded in regular training may be optimal in adolescent team-sport environments.

3.3. Sex-specific effects: focus on female athletes

Several reviews present information on sex-specific effects, particularly in female football players, who represent a high-risk population for ACL and other knee injuries. [3-5, 9, 10] In the adolescent team athlete meta-analysis, the injury-preventive effect of multicomponent programs was stronger in female athletes (IRR 0.56, 95% CI 0.35–0.88) than in males (IRR 0.66, 95% CI 0.55–0.80). [11-15] This suggests that female adolescents may derive particular benefit from NMT programs, possibly due to modifiable neuromuscular and biomechanical risk factors.

A systematic review and meta-analysis specifically targeting female football players included 12 randomised controlled trials (mostly adolescent teams) evaluating exercise-based injury prevention programs. [3-5] Eleven of these interventions were exercise-based, and nine were multicomponent. [3-5] In pooled analyses, multicomponent exercise programs reduced:

Overall (any) injuries: IRR 0.73 (95% CI 0.59–0.91), a 27% reduction. [3-5]

ACL injuries: IRR 0.55 (95% CI 0.32–0.92), a 45% reduction. [3-5]

Hamstring injuries: IRR 0.40 (95% CI 0.17–0.95), a 60% reduction (across single-component and multicomponent strategies). [3-5]

Although reductions in knee, ankle, and hip/groin injuries were also observed, the precision of these estimates was limited, and many individual trials had a high risk of bias. [3-5] Nonetheless, the direction of effect consistently favoured multicomponent programs, and greater reductions in overall and knee injuries were associated with the use of multiple training components. [3-5]

The FAIR consensus review on lower extremity injury prevention in female, athletes further supports these outcomes. [9, 10] Synthesizing data from 82 intervention studies (including 48 randomized controlled trials) and over 154,000 participants, this review concluded that neuromuscular training programs incorporating lower extremity balance, strength, agility, and change-of-direction exercises,

delivered for at least 10 minutes twice per week, reduced lower extremity injury risk in female athletes by approximately 19% (pooled RR 0.81, 95% CI 0.61–1.08; low-certainty evidence). [9, 10]

Together, these results show that multicomponent NMT programs are an effective strategy for reducing lower extremity injuries among female team-sport athletes, including adolescents, with particularly meaningful benefits for ACL and hamstring injuries. [3-5, 9-15]

3.4. Sport-specific evidence in youth soccer and football

Football (soccer) is the most extensively studied sport with respect to exercise-based injury prevention programs. [1-8, 16, 17, 21, 22] A recent umbrella review of meta-analyses reported that the vast majority of systematic reviews on injury prevention programs are focused on soccer, and that specific programs such as FIFA 11+ and FIFA 11+ Kids consistently show protective effects. [16]

A systematic review and meta-analysis of injury prevention programs in youth soccer players analysed 19 studies involving more than 28,000 players. [17, 20] Twelve studies demonstrated positive effects on overall injury incidence, while four found no significant effects. [17, 20] When pooled, injury prevention programs significantly decreased the likelihood of injury with an overall risk ratio of 0.615 (95% CI 0.512–0.739; $p<0.001$). [17, 20] Subgroup analyses showed that age, intervention duration, and type of injury prevention program did not considerably change the overall effect, suggesting that different multicomponent programs can be effective as long as they are implemented with sufficient quality and adherence. [17, 20] Importantly, most studies reported increasing effectiveness with higher adherence or compliance, highlighting the key role of implementation. [17, 20]

In an age-inclusive meta-analysis of multicomponent exercise-based prevention programs among footballers, 15 randomized and cluster-randomized controlled trials comprising over 22,000 players reported RRs of 0.71 (95% CI 0.59–0.85) for overall injuries, 0.82 (95% CI 0.71–0.94) for lower limb injuries, 0.69 (95% CI 0.52–0.90) for knee injuries, and 0.73 (95% CI 0.55–0.96) for ankle injuries. [1, 2] Though this analysis included both youth and adults, the findings are broadly consistent with those found in adolescent-only samples. [1, 2, 11-15, 17, 20]

Umbrella reviews focusing on male soccer players likewise concluded that injury prevention programs based on physical exercise—particularly multicomponent neuromuscular and warm-up protocols—are effective in reducing the incidence of football-related injuries. [16, 21, 22] While these reviews primarily address adult male players, their findings uphold the generalizability of multicomponent NMT strategies across age groups and competition levels. [1, 2, 16, 21, 22]

3.5. Program characteristics: dose, content, and delivery

Across the included reviews, effective injury prevention programs shared several common features regarding dose, content, and delivery:

Multicomponent content: The most efficient interventions integrated multiple components, such as warm-up, jumping/plyometric exercises, strength (with emphasis on hamstrings and core), agility and change-of-direction drills, and balance/proprioceptive training. [3-5, 9-15]

Session duration: Programs with session duration under 20 minutes were at least as effective, and often more effective, than longer sessions. [11-15] In adolescent team athletes, interventions lasting less than 20 minutes per session showed an IRR of 0.59 (95% CI 0.44–0.79), compared with 0.70 (95% CI 0.57–0.86) for longer sessions. [11-15]

Frequency and total dose: Many effective programs prescribed exercises two to three times per week, often as part of regular team warm-ups. [3-5, 9-15, 17] The FAIR consensus suggested that a minimum of 10 minutes twice per week is needed to achieve meaningful reductions in lower extremity injury risk in female athletes. [9, 10]

Integration into training: Successful interventions were typically delivered by coaches or trainers during standard practice sessions, which may facilitate adherence compared with stand-alone sessions. [5, 11-15, 17]

Progression and specificity: Several programs used progressive overload and sport-specific movement tasks to improve neuromuscular control within scenarios resembling game situations (e.g., cutting, landing, pivoting). [3-5, 11-15, 17]

These characteristics suggest that practical, time-efficient, integrated NMT sessions can be embedded within youth team-sport contexts lacking excessive disruption to training schedules.

3.6. Implementation, adherence, and contextual conditions

Despite strong evidence of effectiveness within trial conditions, implementation of sport injury prevention programs in community and school settings remains suboptimal. [17-20] A mixed-method systematic review that combined meta-analysis of adolescent sport injury prevention programs with qualitative and mixed-method studies found key determinants of successful implementation. [18, 19]

This review found that implementing sport injury prevention programs in adolescents provided an approximate 37% risk reduction (IRR = 0.63, 95% CI = 0.53–0.74), but real-world uptake was limited. [18] Meta-aggregation of qualitative and mixed-method data yielded four major sets of synthesised findings:

Players' perceptions and beliefs: Athletes' understanding of injury risk and prevention, perceived usefulness of the program, and motivation to participate influenced adherence. [18, 19]

Coaches as key facilitators: Coaches' knowledge, attitudes, and skills in delivering injury prevention programs were central to successful implementation, illustrating the importance of coach education and buy-in. [18, 19]

Organisational support: Support from clubs, schools, and sport organisations—including scheduling, resources, and leadership—was necessary to embed programs sustainably. [18, 19]

Program characteristics: Programs that were time-efficient, easy to implement, and compatible with existing practice structures were more likely to be adopted and maintained. [18-19]

These implementation themes are consistent with observations from other reviews, which noted that higher adherence and compliance were associated with greater injury reductions in youth soccer and other sports. [9, 10, 17, 20] In contrast, lack of time, insufficient coach training, and perceived interference with performance-oriented practice were common barriers. [17-20]

4. Discussion

4.1. Summary of main findings

This systematic review of systematic reviews and meta-analyses demonstrates that multicomponent neuromuscular training and related exercise-based injury prevention programs have a consistent, clinically meaningful protective effect against lower extremity injuries in adolescent team-sport athletes. Across adolescent-specific studies, such programs reduced total injuries by approximately 35%, lower extremity injuries by about one-third, and ankle injuries by nearly 40%, with additional benefits for knee, acute, and overuse injuries. [11-15] Similar relative risk reductions were observed in youth soccer and in age-mixed football populations. [1, 2, 17, 20]

Evidence in female athletes, particularly in female football, indicates even larger benefits: multicomponent programs reduce ACL injuries by about 45%, overall injuries by around 27%, and hamstring injury risk by 60%. [3-5] These outcomes are reinforced via broader female-focused consensus work indicating that neuromuscular training programs incorporating balance, strength, agility, and change-of-direction exercises, delivered at least twice weekly, can reduce lower extremity injury risk in girls and women. [9, 10] Adolescent female athletes, therefore, represent a priority group for implementation of such programs.

Optimal programs appear to be:

- Multicomponent (strength, plyometrics, balance, agility, movement control);
- Time-efficient (under 20 minutes per session);
- Integrated into regular warm-ups two to three times per week; and
- Delivered with high adherence and adequate progression. [3-5, 9-15, 17]

Importantly, reviews focusing on adolescents highlighted that the magnitude of injury risk reduction in real-life settings depends not only on program content, but also on implementation factors such as players' beliefs, coaches' engagement, and organisational support. [17-20]

4.2. Consequences for youth sport, education, and health promotion

The present synthesis has immediate implications for the management and quality of youth sport programs, in line with the mission of journals emphasising sport, health, and educational aspects. Broad implementation of multicomponent neuromuscular training programs in schools, sports clubs, and academies could: Reduce the burden of lower extremity injuries, particularly serious knee

injuries in adolescent female team sport athletes; [3-5, 11-15] Enhance player availability and performance by decreasing time-loss injuries; [17, 20] Contribute to long-term joint health and sustained participation in physical activity; [3-5, 9, 10] Serve as a structured, evidence-based component of physical education curricula and coach education programs. [18, 19]

From a management and quality perspective, integrating injury prevention into the routine structure of youth sport organisations can be viewed as a quality marker of responsible sport governance and athlete welfare. [6-10, 18, 19] Incorporating neuromuscular training into standard warm-up protocols represents a low-cost, scalable intervention that supports both performance and health outcomes.

4.3. Implementation strategies and barriers.

Despite strong evidence of efficacy, implementation at scale is challenging. [17-20] Key approaches to improve uptake include:

Coach education and empowerment: Coaches are crucial gatekeepers; thus, training them to understand the rationale, content, and progression of NMT programs is essential. [9, 10, 18, 19]

Organisational regulations: Sport clubs, federations, and schools can mandate or incentivise the use of standardised warm-up injury prevention programs as part of licensing or quality assurance frameworks. [18, 19]

Insertion into practice: Programs should be designed to fit effortlessly into existing training structures, ensuring sessions are brief, require minimal equipment, and are compatible with the technical and tactical goals of the session. [3-5, 11-15, 17]

Monitoring and feedback: Simple adherence logs and evaluation methods can help maintain program fidelity and motivate coaches and athletes. [17, 20]

Common barriers—such as perceived lack of time, competing performance priorities, scepticism about efficacy, and lack of support—need to be proactively addressed through communication, policy, and practical support. [17-20]

4.4. Strengths and limitations of the evidence

A major strength of the evidence base is the convergence of findings across multiple independent systematic reviews and meta-analyses that used rigorous methods and covered large, diverse samples, including many thousands of adolescent and youth athletes. [1-15, 17-20] Parallel evidence in adult athletes and different sports further increases confidence in the generalizability of multicomponent NMT strategies. [1, 2, 16, 21, 22]

However, several limitations deserve consideration:

Heterogeneity: Interventions differed in content, duration, frequency, and implementation context, making direct comparisons more complicated and the exact identification of the “best” program design more difficult. [1-5, 9-15, 17]

Risk of bias: Many primary trials exhibited unclear or high risk of bias due to limitations in randomisation, blinding, and injury reporting, and several meta-analyses were rated as low or very low certainty evidence. [1-15, 17]

Overlapping data: Some umbrella and consensus reviews included overlapping sets of trials, limiting the potential for independent pooled estimates at the review level. [16, 21, 22, 9, 10]

Implementation data: While several reviews incorporated qualitative or mixed-methods evidence, detailed implementation outcomes (e.g., fidelity, context) remain underreported in primary trials. [17-20]

The present umbrella review is also limited owing to its reliance on published systematic reviews and meta-analyses rather than the direct analysis of individual trials, and by potential publication bias in the underlying literature. [1-19]

4.5. Future research directions.

Future research ought to prioritise:

- High-quality randomised or cluster-randomised trials in adolescent team sport settings with strong injury surveillance and open reporting; [1-5, 11-15, 17]
- Longer-term follow-up to assess sustained effects, adherence over multiple seasons, and impact on long-term joint health; [3-5, 9-10]
- Comparative effectiveness trials examining different program designs, doses, and delivery modes; [9-15, 17]
- Hybrid effectiveness-implementation studies that evaluate both injury outcomes and implementation strategies in school and community sport systems; [18, 19]
- Specialised interventions for under-studied populations, including younger children, non-elite teams, and athletes in emerging sports. [6-8, 16, 21, 22]

5. Conclusions

Multicomponent neuromuscular training and related exercise-based injury prevention programs provide a solid, evidence-based approach to reducing lower extremity injuries in adolescent team sport athletes, with particularly strong protective effects in female players. [1-5, 9-15, 17, 20] The most effective programs are brief, integrated into regular warm-ups, and include a combination of warm-up, plyometric, strength, agility, and balance training, with adequate frequency and observance. [3-5, 9-15, 17] Successful implementation depends on coach engagement, organisational support, and athlete motivation, and should be a strategic priority for schools, sport clubs, and governing bodies committed to safe and sustainable youth sport participation. [17-20]

Practical implications for coaches, educators, and sport managers

- Adolescent team sport programs should routinely integrate a multicomponent neuromuscular training warm-up (10–20 minutes, at least twice per week) to reduce lower extremity injury risk. [9-15]

- Female adolescent athletes, particularly in football and other pivoting sports, need to be prioritised for such interventions due to their elevated risk of knee and ACL injuries and the large relative benefits observed. [3-5, 9-15]
- Coaches require targeted education and organisational backing to deliver injury prevention programs consistently and effectively. [18, 19]
- Sport organisations and schools can enhance the quality and safety of sport participation by embedding NMT programs into standard practice guidelines, certification requirements, and monitoring systems. [6-10, 17, 18]

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Funding: The study did not receive external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgements: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

All authors have read and agreed with the published version of the manuscript.

Declaration of the use of generative AI and AI-assisted technologies in the writing process: During the preparation of this work, the author used generative AI to assist with grammar and stylistic editing to ensure appropriate academic language and for translation into English. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the final content of the manuscript.

References

1. Obërtinca, R., Hoxha, I., Meha, R. *et al.* Efficacy of Multi-Component Exercise-Based Injury Prevention Programs on Injury Risk Among Footballers of All Age Groups: A Systematic Review and Meta-analysis. *Sports Med* 53, 837–848 (2023). https://doi.org/10.1007/s40279-022-01797-7

2. Emery CA, Meeuwisse WH. The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer: a cluster-randomised controlled trial. Br J Sports Med. 2010;44(8):555–62. https://doi.org/10.1136/bjsm.2010.074377

3. Crossley KM, Patterson BE, Culvenor AG, *et al*Making football safer for women: a systematic review and meta-analysis of injury prevention programmes in 11 773 female football (soccer) players*British Journal of Sports Medicine* 2020;54:1089-1098. http://dx.doi.org/10.1136/bjsports-2019-101587

4. Rössler, R., Junge, A., Bizzini, M. et al. A Multinational Cluster Randomised Controlled Trial to Assess the Efficacy of '11+ Kids': A Warm-Up Programme to Prevent Injuries in Children's Football. Sports Med 48, 1493–1504 (2018). https://doi.org/10.1007/s40279-017-0834-8

5. Bizzini M, Dvorak JFIFA 11+: an effective programme to prevent football injuries in various player groups worldwide—a narrative review*British Journal of Sports Medicine* 2015;49:577-579. https://doi.org/10.1136/bjsports-2015-094765

6. Stephenson SD, Kocan JW, Vinod AV, Kluczynski MA, Bisson LJ. A Comprehensive Summary of Systematic Reviews on Sports Injury Prevention Strategies. *Orthopaedic Journal of Sports Medicine*. 2021;9(10). https://doi.org/10.1177/23259671211035776

7. Myer GD, Sugimoto D, Thomas S, Hewett TE. The Influence of Age on the Effectiveness of Neuromuscular Training to Reduce Anterior Cruciate Ligament Injury in Female Athletes: A Meta-Analysis: A Meta-Analysis. *The American Journal of Sports Medicine*. 2013;41(1):203-215. https://doi.org/10.1177/0363546512460637

8. Steffen K, Emery CA, Romiti M, *et al* High adherence to a neuromuscular injury prevention programme (FIFA 11+) improves functional balance and reduces injury risk in Canadian youth

female football players: a cluster randomised trial*British Journal of Sports Medicine* 2013;47:794-802. https://doi.org/10.1136/bjsports-2012-091886

9. Bullock GS, Räisänen AM, Martin C, *et al* Prevention strategies for lower extremity injury: a systematic review and meta-analyses for the Female, woman and/or girl Athlete Injury pRevention (FAIR) consensus *British Journal of Sports Medicine* 2025;59:1575-1586. https://doi.org/10.1136/bjsports-2025-109910

10. Omi Y, Sugimoto D, Kuriyama S, et al. Effect of Hip-Focused Injury Prevention Training for Anterior Cruciate Ligament Injury Reduction in Female Basketball Players: A 12-Year Prospective Intervention Study. The American Journal of Sports Medicine. 2018;46(4):852-861. https://doi.org/10.1177/0363546517749474

11. Liu H, Liu X, Yin L. Effects of multicomponent exercise injury prevention programs on adolescent team athletes (10-19 years old): a systematic review and meta-analysis. Front Pediatr. 2026 Jan 7;13:1561993. https://doi.org/10.3389/fped.2025.1561993

12. Mendiguchia, J., Ford, K.R., Quatman, C.E. *et al.* Sex Differences in Proximal Control of the Knee Joint. *Sports Med* 41, 541–557 (2011). https://doi.org/10.2165/11589140-000000000-00000

13. McKay D., Broderick C., Steinbeck K. The adolescent athlete: a developmental approach to injury risk. *Pediatr Exerc Sci*. (2016) 28(4):488–500. https://doi.org/10.1123/pes.2016-0021

14. Obërtinca R, Meha R, Hoxha I, *et al*Efficacy of a new injury prevention programme (FUNBALL) in young male football (soccer) players: a cluster-randomised controlled trial *British Journal of Sports Medicine* 2024;58:548-555. https://doi.org/10.1136/bjsports-2023-107388

15. Emery CA, van den Berg C, Richmond SA, *et al* Implementing a junior high school-based programme to reduce sports injuries through neuromuscular training (iSPRINT): a cluster randomised controlled trial (RCT)*British Journal of Sports Medicine* 2020;54:913-919. https://doi.org/10.1136/bjsports-2019-101117

16. Pineda-Escobar, S.; Matias-Soto, J.; García-Muñoz, C.; Martinez-Calderon, J. Protecting Athletes: The Clinical Relevance of Meta-Analyses on Injury Prevention Programs for Sports and Musculoskeletal Body Regions: An Overview of Systematic Reviews with Meta-Analyses of Randomized Clinical Trials. *Healthcare* 2025, *13*, 1530. https://doi.org/10.3390/healthcare13131530

17. Castillo, D., Marqués-Jiménez, D., Bertollo, M. *et al.* A systematic review and meta-analysis of various injury prevention programs in youth soccer players. *BMC Sports Sci Med Rehabil* 17, 190 (2025). https://doi.org/10.1186/s13102-025-01246-8

18. Zhang ZX, Lai J, Shen L, *et al* Effectiveness of exercise-based sports injury prevention programmes in reducing injury rates in adolescents and their implementation in the community:

a mixed-methods systematic review*British Journal of Sports Medicine* 2024;58:674-684. https://doi.org/10.1136/bjsports-2023-107717

19. Guilfoyle L , Kenny IC , O'Sullivan K , et al . Coaches of youth field sports as delivery agents of injury prevention programmes: how are we training the Trainers? A Scoping review. Br J Sports Med 2024;58:144–53. https://doi.org/10.1136/bjsports-2023-106934

20. Castillo, D., Marqués-Jiménez, D., Bertollo, M. *et al.* A systematic review and meta-analysis of various injury prevention programs in youth soccer players. *BMC Sports Sci Med Rehabil* 17, 190 (2025). https://doi.org/10.1186/s13102-025-01246-8

21. Joel Barrera, Antonio J. Figueiredo, Filipe Manuel Clemente, Adam Field, Luis Valenzuela, Hugo Sarmento. Injury Prevention Programmes in Male Soccer Players: An Umbrella Review of Systematic Reviews. Journal of Men's Health. 2022. 18(10);1-17. DOI: 10.31083/j.jomh1810200

22. Hägglund M, Waldén M, Magnusson H, *et al*Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study*British Journal of Sports Medicine* 2013;47:738-742. https://doi.org/10.1136/bjsports-2013-092215