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A systematic review and network meta-analysis on the effectiveness of exercise-based interventions for reducing the injury incidence in youth team-sport players. Part 2: An analysis by movement patterns

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A systematic review and network meta-analysis on the effectiveness of exercise-based interventions for reducing the injury incidence in youth team-sport players. Part 2: An analysis by movement patterns

ABSTRACT

Objectives: The objectives of this network meta-analysis were: a) to estimate and compare the pooled effects of some injury prevention programs (IPPs) whose exercise-based components were categorized using a movement pattern-specific taxonomy on reducing overall and some specific body regions (lower extremity, thigh, knee, and ankle) injury incidences in youth team sport athletes, and b) to explore the individual effects of these components on the injury incidence rates (IIRs) previously mentioned.

Materials and Methods: Searches were performed in PubMed, Web of Science, SPORTDiscus, and Cochrane Library. Eligible criteria were: exercise-based interventions comprised of exercises involving athletic motor skill competencies and evaluated against a control group, overall IIRs were reported, and youth (≤ 19 years old) team sport players. For the current analysis, a taxonomy based on movement patterns was employed for exercise component identification (upper body pushing and pulling; lower body concentric and eccentric; core; mechanics; acceleration; and lower body stability). Pooled effects were calculated by Frequentist random effects pairwise and network meta-analyses.

Results: Nineteen studies were included. Most of the IPPs exhibit risk reduction when compared to their control groups on overall, lower extremity, and ankle injuries. Interventions comprised of lower body concentric and eccentric, core, mechanics, and lower body stability exercises were the most effective measures for reducing these injuries. None of the IPPs demonstrated to be effective for reducing thigh injuries, and contradictory results were found for knee injuries. Individual analysis at component level revealed that the lower body (bilateral and unilateral, concentric, and eccentric) component was the only one associated with a significant reduction on overall injuries.

Conclusions: Indirect evidence suggests that interventions incorporating lower body concentric and eccentric, core, mechanics, and lower body stability exercises might be the most effective for reducing overall, lower extremity, and ankle injuries in youth team sports.

KEYWORDS: injury prevention, ankle, athletic motor skills, mechanics, adolescence, young athletes, soccer.

KEY MESSAGES

- The categorization of exercise components based on the movement patterns might, a priori, be considered a criterion more closely associated with the injury phenomenon.

- Lower body concentric and eccentric, core, mechanics, and lower body stability exercises should be incorporated to any training program aimed at minimizing the risk of injury in youth.

- The ineffectiveness of interventions on the reduction of thigh injuries reveals the need for reconsideration of injury prevention strategies.

1. INTRODUCTION

As documented in Part 1 (1), injury prevention programs (IPPs) incorporating both single (strength and flexibility) and multiple exercise components (e.g., FIFA 11+ (2) and FIFA 11 Kids+ (3)) which are regularly performed (for at least 12 weeks) may significantly reduce the risk of injury in youth (i.e., adolescents ≤ 19 years old) team sport athletes (mainly soccer players) by approximately a third. The findings from Part 1 of this series of articles, along with those presented in previous systematic reviews and meta-analyses (4–7), also underscore a significant degree of heterogeneity in the magnitude of risk mitigation effects associated with these IPPs across individual trials. Consequently, the aforementioned claim regarding the effectiveness of IPPs should be approached with caution as it appears to be moderated by specific factors. Identifying and quantifying the moderating effects of these factors using robust statistical techniques is a fundamental task that must be addressed prior to developing comprehensive best-practice guidelines for designing effective IPPs in the future.

It has been suggested that the content (especially the types of exercise-based components included) of the IPPs is a primary factor (albeit not the only one) that may potentially explain (at least partially) the documented high heterogeneity in the magnitude of their prophylactic effects. Previous systematic reviews and meta-analyses (6,7), including the network meta-analysis conducted in Part 1 (1), have thoroughly investigated the existence of an optimal combination of exercise-based components to be incorporated into IPPs that may result in maximizing the risk mitigation effects in youth team sport athletes. In pursuit of this objective, these studies categorized the exercise-based components according to the classic taxonomy of health- and sport-related components of physical fitness, defining specific types such as strength, stability, plyometrics, flexibility/mobility, speed & agility, and warm-up drills. However, their findings suggest that the use of this classic taxonomy based on macro elements related to physical fitness to categorize the different exercise-based components might not be sensitive enough to detect inter-IPP differences in their effectiveness for reducing the risk of injury in such a cohort. It should be highlighted that these studies observed certain tendencies in their results that seem to indicate that exercises targeting muscle strength, joint stability, and mobility might constitute the cornerstone of any IPP (1,7). Despite this emerging evidence, the question of whether there is (or not) an optimal combination of these to maximize the effectiveness of IPPs in reducing injuries sustained by youth team sport athletes is still unanswered.

Epidemiological data has confirmed that the most burdensome injuries diagnosed in youth team sports predominantly result from non-contact or indirect contact mechanisms (8,9). Recent studies, utilizing systematic video analysis, have recognized specific situational patterns for professional adult team sport athletes (mainly in soccer, basketball, handball, and rugby match-play) who suffered an injury (predominantly anterior cruciate ligament [ACL] tears, muscle [hamstrings] strains, and Achilles tendon ruptures), including 1) pressing and tackling, 2) kicking, 3) linear acceleration or high-speed running, 4) changing direction or cutting maneuvers in combination with deceleration, and 5) landing from a jump (10–16). These video analysis studies have also acknowledged that a significant proportion of injuries in team sports appears to be associated with the adoption of aberrant multiplanar movement patterns (especially when the lower extremity is fixed [i.e., weight-bearing] on the ground) during the previously mentioned inciting events. In particular, the most frequently cited movement patterns for injury incidence primarily involved the adoption of one or a combination of some of the following actions: excessive trunk lateral inclination in the frontal plane and knee valgus motions (i.e., a multi-joint and multiplane movement pattern comprised of varying degrees of hip adduction and internal rotation and knee abduction and external rotation joint kinematics (17)), limited or exacerbated hip and knee flexion, and the adoption of a large base of support to the center of mass distance (10–14). Although the findings reported by these studies came from videos recorded in national (domestic leagues) and international tournaments where professional teams competed, some evidence supports the existence of similar injury situational patterns in their youth counterparts (18). Furthermore, some biomechanical studies (19–21) have supported these findings as they are shown that, independent of the age and sex of the athlete, the adoption of these abnormal movement patterns (e.g., excessive knee valgus motion, limited hip and knee flexion) during the execution of explosive tasks (e.g., rapid changes of direction, landing from a jump) increases substantially the load (e.g., knee abduction moment) to be held by soft tissue (e.g., ACL), which increases the likelihood of damage it.

The existence of potentially injury-prone movement patterns in team sports might justify the use of a movement pattern-specific taxonomy to categorize the exercise-based components included in an IPP. In this sense, Moody et al. (22) identified eight primary movement patterns that athletes should master before developing more complex sport-specific skills: 1) lower body bilateral (concentric and eccentric); 2) lower body unilateral (concentric and eccentric); 3) upper body pushing (vertical and horizontal); 4) upper body pulling (vertical and horizontal); 5) throwing, catching, and grasping; 6) anti-rotation and core bracing; 7) jumping, landing and rebounding mechanics; 8) acceleration, deceleration, and reacceleration. The exercises incorporated into published IPPs have been chosen, among other criteria, considering as target population athletes with less than 6-8 years of training age (defined as the amount of time accumulated from both periodic and longitudinal participation in training programs and sport-related activities (23)) whose movement competency and physical fitness is supposed to require gradual improvements to promote safe long-term athlete development and regular sport practice later in life, such as kids (e.g., FIFA 11+ Kids) and adolescents (e.g., FIFA 11+ and Harmoknee). Consequently, these exercises encompass the execution of relatively easy-to-perform movements that could be labeled into one of the eight categories of primary movement patterns just mentioned (e.g., squat = 1. lower body bilateral; broad jump = 6. jumping, landing, and rebounding mechanics; frontal and lateral planks = 5. anti-rotation and core bracing). Therefore, the use of this movement pattern-specific taxonomy to categorize the exercise-based components included in an IPP in a moderator analysis within a network meta-analysis might shed light on determining whether there may be a specific (or some) combination of these that allows for maximizing the risk mitigation effects of the IPPs (second level of concretion [please read the method section of Part 1 for clarification]) and whether there are components whose individual prophylactic effects are larger than others (third level of concretion).

Therefore, the main objectives of this study were to conduct a network meta-analysis a) to estimate and compare the pooled effects of some IPPs whose exercise-based components were categorized using a movement pattern-specific taxonomy on reducing overall and specific body regions (lower extremity, thigh, knee, and ankle) injury incidence in youth team sport athletes as well as b) to explore the individual effects of these components on the injury incidences previously mentioned.

2. METHODS

The core methodology and primary results (pooled effects of IPPs on reducing overall and some specific body region injury incidences [first level of concretion]) of this systematic review and network meta-analysis were compiled in Part 1 of this series (1). The protocol for this network meta-analysis was also registered in the PROSPERO International Prospective Register of Systematic Reviews (http://www.crd.york.ac.uk/PROSPERO/), registration number CRD42020152487. Likewise, the analysis conducted in this study under a new taxonomy is fully described and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (24) along with the specific extension for network meta-analyses (PRISMA-NMA) (25). The PRISMA-NMA checklist can be found in the online supplementary file 1.

2.1. Study selection

Eligibility criteria were established and agreed upon by all authors based on the population, intervention/indicator, comparator/control, and outcome (PICOS) framework (25) (please see online supplementary file 2 for further details). To be included in the current analysis, studies were required to be full-text articles published in a peer-reviewed journal before January 2024 and satisfy the following criteria:

- Population (P): The study population comprised youths (males and females) aged 19 years or younger participating in structured/organized team sports programs at a competitive level.
- Intervention (I): An IPP, defined as exercise-based strategies comprised of one or multiple exercises involving athletic motor skill competencies that had the aim of reducing injury incidence, was evaluated with no co-interventions provided.
- Comparator (C): The study included a control group of similar-age participants either performing usual practice routine or sham exercises without a specific focus on modifiable lower extremity injury risk factors (e.g., neuromuscular control) but still exposed to normative existing practices.
- Outcome (O): Epidemiological data (injury incidence, number of injuries, and/or hours of sport exposure) of overall injuries (i.e., the total number of injuries prospectively recorded through the follow-up period of the study) were provided. Injuries were defined in line with Fuller et al's. (26) time-loss and medical attention definitions. Thus, all types of injuries that met these definitions were included.
- Study design (S): An analytical prospective design was employed, encompassing randomized controlled trials (RCTs), quasi-experimental trials, cohort studies, and observational studies.

When eligibility could not be confirmed from the reported data, the authors were contacted for additional information. Interventions using protective devices (i.e., braces, tapes), literature reviews, abstracts, editorial commentaries, and letters to the editor were excluded. Articles not peer-reviewed or not written in English or Spanish were also excluded. As in Part 1, studies reporting incidences for specific injuries (e.g., anterior cruciate ligament of the knee tears, hamstring muscle strains), but not for overall incidents, were discarded.

As the data for this study were obtained from previous trials where participants had already provided informed consent, ethical approval from a research ethics committee was not required for this investigation.

2.2. Search strategy

A systematic computerized search was conducted up to 15th January 2024 in the databases PubMed, Web of Science, SPORTDiscus, and Cochrane Library. Two reviewers (FJR-P and AL-V) independently selected studies for inclusion in a two-step process. First, studies were screened based on title and abstract. In the second stage, full-text studies were reviewed to identify those studies that met the eligibility criteria. A study was excluded immediately once it failed to meet a single inclusion criterion. Disagreements were resolved through consensus or by consulting a third reviewer (FA). A full description of the study search and selection process can be found in Part 1 of this systematic review (1). The search terms and Boolean operators used for each of the databases are also presented in the online supplementary file 3.

2.3. Data extraction

For this second part, the same codebook as in Part 1 to codify the basic moderator variables of the eligible studies was used, encompassing general study descriptors, study population, characteristics of the interventions, and epidemiological data. When applicable, the authors of the included studies were contacted to provide clarifications or access to raw data. Online supplementary file 4 displays the moderator variables coded separately by category.

For the primary purpose of this network meta-analysis, the incidence was extracted for reported "overall or total injuries". If the incidence was not reported, it was calculated by dividing the number of injuries by the total hours of exposure for each intervention and control groups. The number of injuries by anatomic location, type of injury, severity, and mechanisms according to the operational definitions reported by Fuller et al. (26) was also recorded to explore possible sub-analyses.

Regarding the categorization of exercise components integrated into the IPP, a different taxonomy from the one used in Part 1 was employed for the current analysis. Specifically, the movement pattern-specific taxonomy described by Moody et al. (22) was utilized here. This taxonomy identifies eight primary movement patterns that athletes should master before developing more complex sport-specific skills: 1) lower body bilateral (concentric and eccentric); 2) lower body unilateral (concentric and eccentric); 3) upper body pushing (vertical and horizontal); 4) upper body pulling (vertical and horizontal); 5) throwing, catching, and grasping; 6) anti-rotation and core bracing; 7) jumping, landing and rebounding mechanics; and 8) acceleration, deceleration, and reacceleration.

Additionally, a new category named lower body stability was created given the high popularity of exercises such as single leg balance, squatting on unstable surfaces, and cross-country skiing in the majority of the interventions analyzed.

The difficulty in distinguishing lower body unilateral exercises from bilateral exercises as well as upper body pushing from pulling exercises in most interventions (due to poor reporting) led to grouping both lower body categories into a single one named "lower body concentric and eccentric", and both upper body categories into an unique one called "upper body pushing and pulling". Due to the characteristics of the programs included in this research, the throwing, catching, and grasping category was also not considered in our study. Taking all this into consideration, the following movement patterns were identified: upper body pushing and pulling, lower body concentric and eccentric, core (anti-rotation and core bracing), mechanics (change of direction [COD], jumping and landing, and rebounding), acceleration (including deceleration, and re-acceleration), and lower body stability. Thus, the following eleven interventions were finally defined for the subsequent analysis:

1) Control
2) Lower body concentric and eccentric + Core + Mechanics + Acceleration + Lower body stability.
3) Upper body pushing and pulling + Lower body concentric and eccentric + Core + Mechanics + Lower body stability.
4) Upper body pushing and pulling + Lower body concentric and eccentric + Core.
5) Lower body concentric and eccentric + Core + Mechanics + Lower body stability.
6) Lower body concentric and eccentric + Core + Mechanics.
7) Core + Lower body stability.
8) Lower body concentric and eccentric + Mechanics + Acceleration + Lower body stability.
9) Upper body pushing and pulling + Lower body concentric and eccentric + Lower body stability.
10) Core.
11) Upper body pushing and pulling + Lower body concentric and eccentric + Core + Mechanics + Acceleration + Lower body stability.

A detailed description of each single exercise component is provided in the online supplementary file 4. Each study was classified as including a specific movement pattern if they described at least one exercise pertaining to the pattern definition. It should be noted that the order of appearance of each single movement pattern in IPPs was not considered but just its presence. All the data extraction and categorization of exercises by movement patterns was conducted by two independent reviewers (FJR-P and AL-V). As before, disagreements were resolved through consensus or by consulting a third reviewer (FA).

2.4. Statistical analyses

The statistical analysis was structured into two stages. In the first stage, separate random-effects network meta-analyses were conducted for the comparison between each type of active program (IPPs) and the control group as well as between the different IPPs within each kind of injury for which there were at least 10 estimates: overall, lower extremity, thigh, knee, and ankle injuries. Although the statistical analyses were performed using the logarithmic transformation, all tables and figures show the overall estimates and their respective confidence intervals (CIs) once back-transformed to the incidence rate ratio (IRR) metric for facilitating interpretation. In the second stage, a random-effects network meta-analysis at the component levels (i.e., upper body pushing and pulling, lower body concentric and eccentric, core, mechanics, acceleration, and lower body stability) was conducted for overall injuries.

To do this, injury incidence rates (IIRs) per 1000 hours of player exposure were extracted from the included studies. If IIRs were not specifically reported, they were, if possible, calculated from the available raw data using the following formula: IIR = 1000 × (∑injuries/∑exposure hours).

All meta-analyses were carried out within a Frequentist framework. All resulting networks were star-shaped so that there was no potential for inconsistency among direct and indirect evidence. The analyses were performed in *R*, using the metafor and netmeta packages (27–29). The analysis codes are available at https://data.mendeley.com/datasets/hg4m522fc5/1.

3. RESULTS

3.1. Descriptive characteristics of the studies

A total of 4635 references were identified with all search strategies, as part of the primary review (Part 1). Of these, 19 involved an exercise intervention including the mentioned athletic motor skill competencies and thus, were included in the current analysis (2,3,30–46). Figure 1 shows the flow chart of the selection process of the studies.

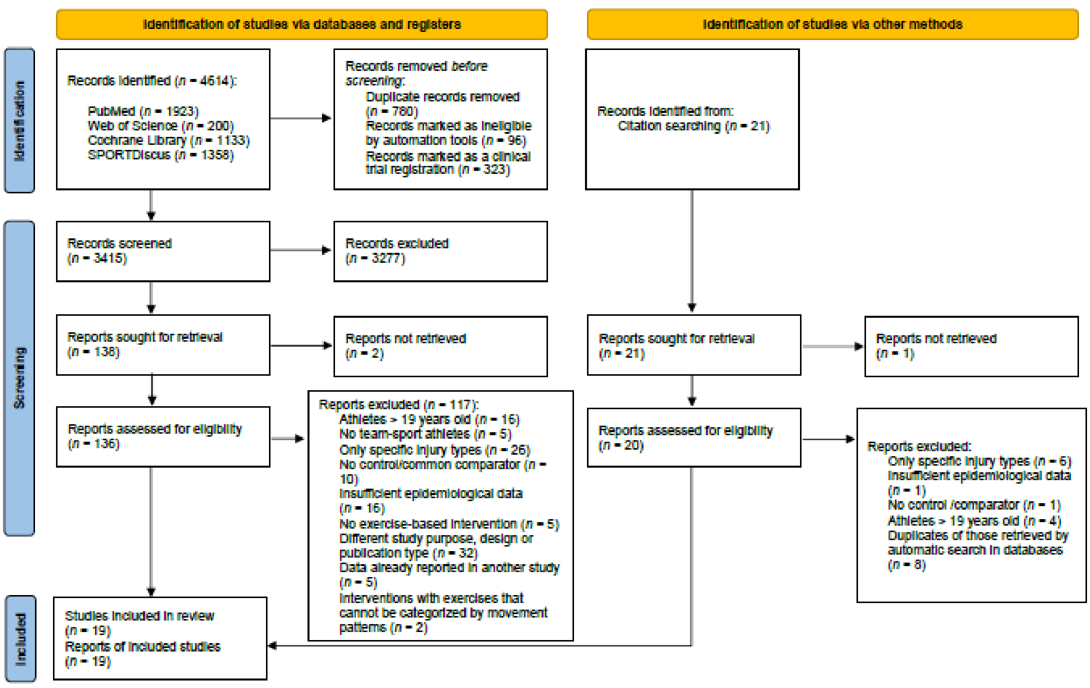

Figure 1PRISMA flow diagram of the selection of studies for this systematic review and network meta-analysis.

The included studies were carried out between 1999 and 2023. The total sample size was 17987 youth team sport athletes, 9556 for the intervention groups, and 8431 for the control groups. In 8 studies, both male and female athletes were examined (3,30,38–43), while 8 studies focused on male athletes (31,34–37,44–46), and 3 trials were on females only (2,32,33). All trials studied team sport athletes, with soccer (2,3,31,32,34–37,42,45) being the most common.

3.2. Type and components of the injury prevention programs

Table 1 summarizes the characteristics of the IPPs included in the overall analysis. All but one (45) of the interventions included exercises involving multiple movement patterns. The most common movement patterns in IPPs were lower body concentric and eccentric (17/19 studies) (2,3,30–42,44,46) and core (anti-rotation and core bracing) (17/19 studies) (2,3,31,32,34–46) while upper body pushing and pulling exercises were used the least (6/19 studies) (3,33,35–38).

Table 1. Component breakdown of injury prevention programs according to specific movement patterns.

Reference *Sport, sex, age*	Upper body pushing and pulling	Lower body concentric and eccentric	Core (anti-rotation and core bracing)	Mechanics (COD, jumping and landing, and rebounding)	Acceleration (incl. deceleration, and re-acceleration)	Lower body stability
Achenbach et al. (2017) *Handball, Mix, age IG: 14.9 (0.9); age CG: 15.1 (1)*	No.	Yes. Nordic hamstring	Yes. Plank, side plank	Yes. Multidirectional single-leg jumps, ice-skater jump, jump run	No.	Yes. SL stabilisation
Åkerlund et al. (2020) *Floorball, Mix, age IG: 13.6 (1.1); age CG: 13.2 (1.3)*	No.	Yes. SL/DL squat, pelvic lift, forward lunge	Yes. Prone/side plank	Yes. SL hop forward/backward, side-to-side hop (SL landing), DL jump with ball header	No.	No.
Al Attar et al. (2023) *Soccer, Male, age IG: 7-13 (range); age CG: 7-13 (range)*	Yes. Press-ups, spiderman	Yes. Spiderman	Yes. Press-ups, spiderman	Yes. Skating jumps, SL jumps	No.	Yes. “Alertness” running game, SL stance

Barboza et al. (2019)[1] *Field hockey, Mix, age IG: 11.5 (1.5); age CG: 12.9 (1.9)*	No.	Yes. SL/DL squats, walking lunges, etc.	Yes. Plank, skater figure, etc.	Yes. SL/DL forward, vertical, and lateral jumps, skating jumps, etc.	Yes. Dribbling, sprint, etc.	Yes. Skater figure, cross-country skiing
Emery et al. (2010) *Indoor soccer, Mix, age IG: 13-18 (range); age CG: 13-18 (range)*	No.	Yes. Nordic hamstring, walking lunges, calf raises	Yes. Abdominal strength exercise	Yes. SL jumps	No.	Yes. SL balance, balance exercises using wobble boards
Emery et al. (2007) *Basketball, Mix, age IG: 13-18 (range); age CG: 12-18 (range)*	No.	No.	Yes. Isometric contraction of abdominal and gluteal muscles	No.	No.	Yes. Balance exercises using wobble boards

Hislop et al. (2017)[1] *Rugby, Male, age IG: 16 (1.2); age CG: 15.9 (1.1)*	No.	Yes. Lunges, Nordic hamstring, etc.	Yes. Side bridge, static side press up with perturbation, etc.	Yes. SL/DL jumps, planned plant and cut, etc.	Yes. Side shuffle, diagonal side shuffle, etc.	Yes. SL balance
Imai et al. (2018) *Soccer, Male, age IG: 12-14 (range); age CG: 12-14 (range)*	No.	No.	Yes. Bird dog (hand-knee), elbow-toe with raised arm and leg, and back bridge with one leg raised	No.	No.	No.
Longo et al. (2012) *Basketball, Male, age IG: 13.5 (2.3); age CG: 15.2 (4.6)*	No.	Yes. Nordic hamstring, squats	Yes. Plank, side plank	Yes. Vertical, lateral and box jumps, running and cutting	Yes. Quick run, running over pitch, bounding run	Yes. SL balance
Olsen et al. (2005) *Handball, Mix, age IG: 16.3*	No.	Yes. Nordic hamstring, DL squat, SL/DL squat on unstable surface	No.	Yes. Jump shot landing, bounding, forward jumps, planting and	Yes. Speed runs, forward running with intermittent stops	Yes. DL ball pass unstable surface, SL

(0.6); age CG: 16.2 (0.6)				cutting		squat unstable surface, DL squat unstable surface, ball bounce with eyes closed unstable surface, perturbations on unstable surface
Owoeye et al. (2014) *Soccer, Male, age IG: 17.8 (0.9); age CG: 17.5 (1.1)*	No.	Yes. Nordic hamstring, squats	Yes. Plank, side plank	Yes. Vertical, lateral and box jumps, running and cutting	Yes. Quick run, running over pitch, bounding run	Yes. SL balance
Rössler et al. (2018) *Soccer, Mix, age IG: 10.8 (1.4); age CG: 10.7 (1.4)*	Yes. Press-ups, spiderman	Yes. Spiderman	Yes. Press-ups, spiderman	Yes. Skating jumps, SL jumps	No.	Yes. “Alertness” running game, SL stance

Soligard et al. (2008) *Soccer, Female, age IG: 15.4 (0.7); age CG: 15.4 (0.7)*	No.	Yes. Nordic hamstring, squats	Yes. Plank, side plank	Yes. Vertical, lateral and box jumps, running and cutting	Yes. Quick run, running over pitch, bounding run	Yes. SL balance
Steffen et al. (2008) *Soccer, Female, age IG: 15.4 (0.8); age CG: 15.4 (0.8)*	No.	Yes. Nordic hamstring	Yes. Prone/side plank	Yes. SL hop forward/backward, side-to-side hop, bounding	Yes. Zigzag shuffle	Yes. Cross-country skiing, SL stance chest pass, SL stance forward bend, SL stance figure-of-8
Verhagen et al. (2023)[1] *Volleyball, Mix, age IG: 12.9 (1.6); age CG: 12.6 (1.7)*	Yes. Shoulder muscle training exercises with elastic bands, etc.	Yes. Squats, walking lunges, etc.	Yes. Prone/side plank, superman, etc.	Yes. Squat jumps back/forward/sideways, drop jumps, etc.	Yes. Relay race, acceleration/deceleration, etc.	Yes. SL balance, SL balance with ball pass, etc.
Wedderkopp et al. (1999) *Handball,*	Yes. Functional strength training for all major	Yes. Functional strength training for all major	No.	No.	No.	Yes. Exercises using ankle

Female, age IG: 16-18 (range); age CG: 16-18 (range)	muscle groups	muscle groups				discs
Zarei et al. (2018) *Soccer, Male, age IG: 15.3 (0.6); age CG: 15.5 (0.7)*	No.	Yes. Nordic hamstring, squats	Yes. Plank, side plank	Yes. Vertical, lateral and box jumps, running and cutting	Yes. Quick run, running over pitch, bounding run	Yes. SL balance
Zarei et al. (2019) *Soccer, Male, age IG: 12.1 (1.8); age CG: 12.2 (1.7)*	Yes. Press-ups, spiderman	Yes. Spiderman	Yes. Press-ups, spiderman	Yes. Skating jumps, SL jumps	No.	Yes. "Alertness" running game, SL stance
Zouita et al. (2016) *Soccer, Male, age IG: 13-14 (range); age CG: 13-14 (range)*	Yes. Multiple-joint strength exercises, such as the bench press	Yes. Multiple-joint strength exercises, such as the squat	Yes. Sit-ups	No.	No.	No.

3.3. Inference

3.3.1. *Multiple comparisons between the injury risk mitigation pooled effects of the different IPPs and with the control group*

3.3.1.1. Overall injuries

The network graph built for the dependent variable overall injury (figure 2a) shows that all the IPPs (*n* = 10 [(labels 2-11]) incorporated into the network meta-analysis were directly compared with the control group in the 19 primary studies included (2,3,30–46), whereas only indirect evidence was available for comparisons between the remaining IPPs (i.e., between the active programs). All programs except programs 5 (lower body concentric and eccentric + core + mechanics + lower body stability) (IRR = 0.77 [95%CI = 0.58 to 1.01]) and 7 (core + lower body stability) (IRR = 0.82 [95%CI = 0.65 to 1.04]) were more effective than the control group, as can be seen in forest plot presented in figure 3a, where the estimates of the network meta-analysis for each comparison are presented alongside their CIs. The most effective programs for overall injuries when compared to control group were programs 9 (upper body pushing and pulling + lower body concentric and eccentric + lower body stability) (IRR = 0.26 [95%CI = 0.15 to 0.46]), program 4 (upper body pushing and pulling + lower body concentric and eccentric + core) (IRR = 0.30 [95%CI = 0.1 to 0.93]), and program 8 (lower body concentric and eccentric + mechanics + acceleration + lower body stability) (IRR = 0.49 [95%CI = 0.39 to 0.63]). Table 2 presents the network meta-analysis estimates for the 55 possible pair-wise comparisons between programs.

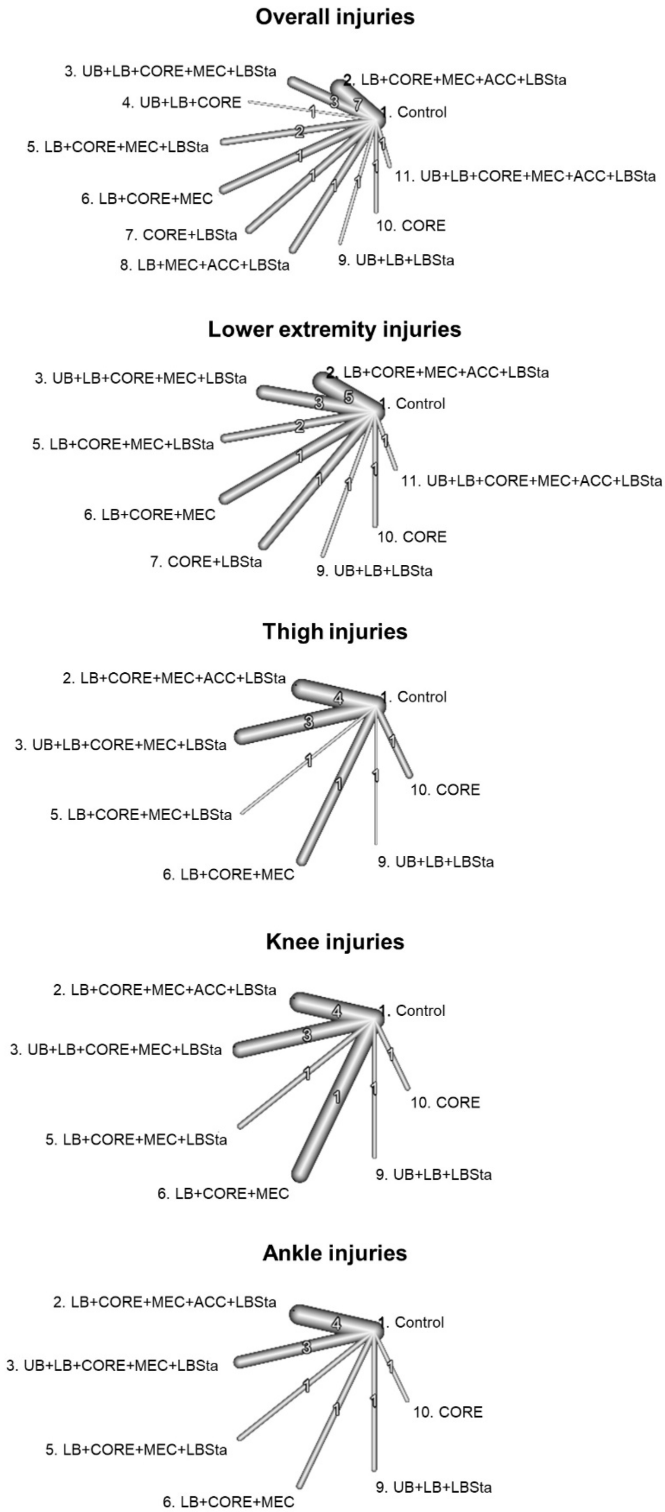

Figure 2Network graphs for the direct evidence comparing programs for overall, lower extremity, thigh, knee, and ankle injuries.

Legend: UB: upper body pushing and pulling; LB: lower body concentric and eccentric; CORE: core (anti-rotation and core bracing); MEC: mechanics (change of direction [COD], jumping and landing, and rebounding); ACC: acceleration (including deceleration, and re-acceleration); LBSta: lower body stability.

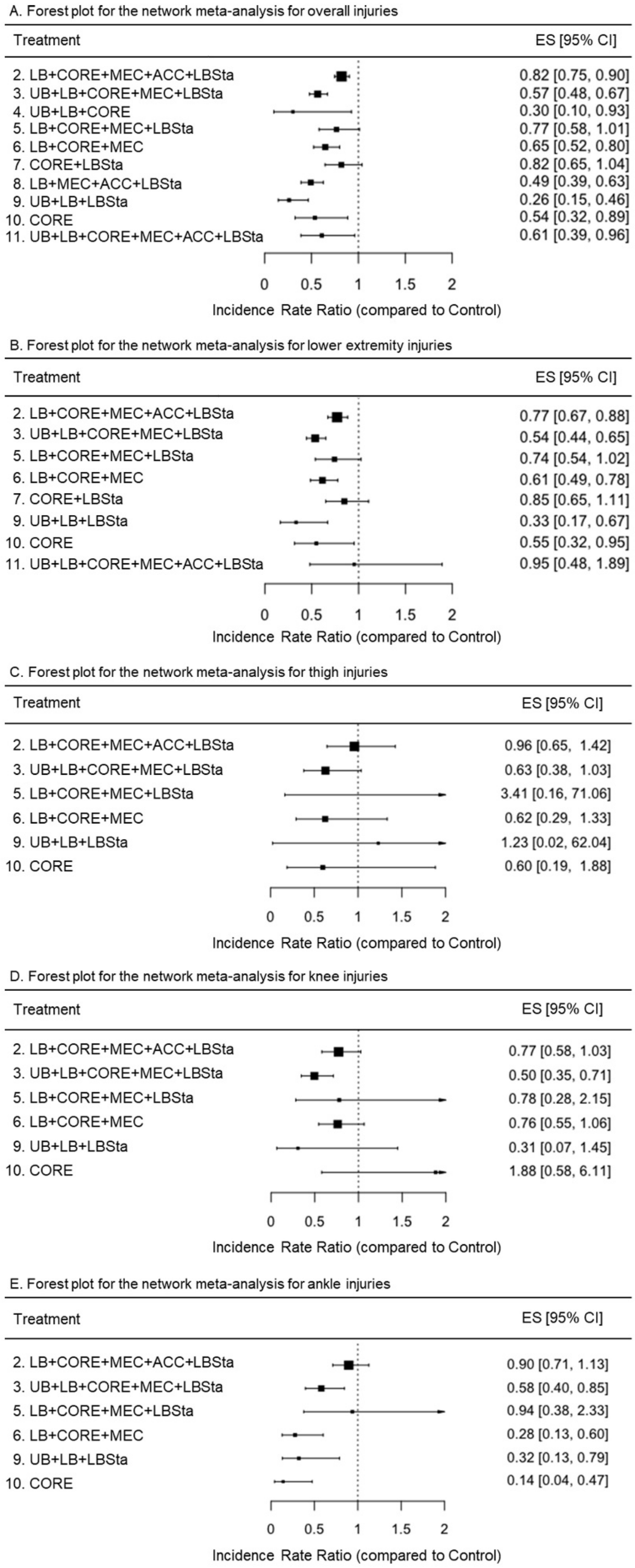

Figure 3Forest plots for the random-effects network meta-analyses conducted for overall, lower extremity, thigh, knee, and ankle injuries.

Legend: UB: upper body pushing and pulling; LB: lower body concentric and eccentric; CORE: core (anti-rotation and core bracing); MEC: mechanics (change of direction [COD], jumping and landing, and rebounding); ACC: acceleration (including deceleration, and re-acceleration); LBSta: lower body stability. Values below 1 favor the intervention over the control (treatment 1).

Table 2. Results of the network meta-analysis for overall injuries: Estimates and 95% confidence intervals for comparisons between each pair of injury prevention programs (programs in rows vs. programs in columns).

Program											
1	1										
2	0.821 [0.746, 0.903]	2									
3	0.566 [0.479, 0.67]	0.69 [0.568, 0.837]	3								
4	0.302 [0.098, 0.925]	0.368 [0.119, 1.132]	0.533 [0.172, 1.655]	4							
5	0.766 [0.581, 1.011]	0.934 [0.697, 1.252]	1.354 [0.979, 1.871]	2.54 [0.801, 8.055]	5						
6	0.647 [0.524, 0.8]	0.788 [0.625, 0.995]	1.143 [0.872, 1.498]	2.144 [0.685, 6.708]	0.844 [0.596, 1.196]	6					
7	0.819 [0.645, 1.039]	0.997 [0.771, 1.29]	1.446 [1.08, 1.936]	2.713 [0.863, 8.531]	1.068 [0.741, 1.539]	1.265 [0.92, 1.74]	7				
8	0.493 [0.388, 0.625]	0.6 [0.464, 0.776]	0.87 [0.65, 1.165]	1.632 [0.519, 5.134]	0.643 [0.446, 0.926]	0.761 [0.553, 1.047]	0.602 [0.429, 0.843]	8			
9	0.261 [0.147, 0.465]	0.318 [0.177, 0.571]	0.461 [0.253, 0.841]	0.865 [0.245, 3.052]	0.341 [0.18, 0.646]	0.404 [0.218, 0.746]	0.319 [0.171, 0.595]	0.53 [0.284, 0.99]	9		
10	0.536 [0.325, 0.886]	0.654 [0.392, 1.09]	0.948 [0.558, 1.609]	1.778 [0.521, 6.071]	0.7 [0.395, 1.242]	0.829 [0.481, 1.43]	0.655 [0.376, 1.143]	1.089 [0.625, 1.899]	2.055 [0.956, 4.414]	10	
11	0.61 [0.387, 0.96]	0.743 [0.467, 1.181]	1.077 [0.664, 1.747]	2.02 [0.603, 6.768]	0.796 [0.468, 1.353]	0.942 [0.571, 1.554]	0.745 [0.446, 1.243]	1.238 [0.741, 2.066]	2.335 [1.121, 4.863]	1.136 [0.578, 2.236]	11

Note. Program 1 = Control; Program 2 = Lower body concentric and eccentric + Core + Mechanics + Acceleration + Lower body stability; Program 3 = Upper body pushing and pulling + Lower body concentric and eccentric + Core + Mechanics + Lower body stability; Program 4 = Upper body pushing and pulling + Lower body concentric and eccentric + Core; Program 5 = Lower body concentric and eccentric + Core + Mechanics + Lower body stability; Program 6 = Lower body concentric and eccentric + Core + Mechanics; Program 7 = Core + Lower body stability; Program 8 = Lower body concentric and eccentric + Mechanics + Acceleration + Lower body stability; Program 9 = Upper body pushing and pulling + Lower body concentric and eccentric + Lower body stability; Program 10 = Core; Program 11 = Upper body pushing and pulling + Lower body concentric and eccentric + Core + Mechanics + Acceleration + Lower body stability. Values below 1 favor the row intervention.

3.3.1.2. Lower extremity injuries

The network meta-analysis directly compared eight IPPs (labeled 2, 3, 5-7, 9-11) and the control group using 15 primary studies (2,3,31–33,35,37–43,45,46) (figure 2b); however, only indirect evidence was available for comparisons between the remaining IPPs. All programs except programs 5 (lower body concentric and eccentric + core + mechanics + lower body stability), 7 (core + lower body stability), and 11 (upper body pushing and pulling + lower body concentric and eccentric + core + mechanics + acceleration + lower body stability) were more effective than the control group at reducing lower extremity IIRs, as can be seen in forest plot presented in figure 3b. The most effective IPP when compared to control group was program 9 (upper body pushing and pulling + lower body concentric and eccentric + lower body stability) (IRR = 0.33 [95%CI = 0.17 to 0.67]). Supplementary file 5 presents the network meta-analysis estimates for the 36 possible pair-wise comparisons between programs.

3.3.1.3. Thigh injuries

The network graph presented in Figure 2c shows that six IPPs (labels 2, 3, 5, 6, 9, 10) included in the network meta-analysis were directly compared with the control group in the 11 primary studies incorporated (2,3,31–33,35,37,39,40,45,46), whereas only indirect evidence was available for comparisons between the remaining IPPs. None of the programs was more effective than control group, as can be seen in the forest plot presented in Figure 3c. Supplementary file 5 presents the network meta-analysis estimates for the 21 possible pair-wise comparisons between programs.

3.3.1.4. Knee injuries

The network graph shown in Figure 2d demonstrates that six IPPs (labels 2, 3, 5, 6, 9, 10) included in the network meta-analysis were directly compared with the control group in the 11 primary studies incorporated (2,3,31–33,35,37,39,40,45,46). However, only indirect evidence was available for comparisons between the remaining IPPs. Of these six IPPs, only program 3 (upper body pushing and pulling + lower body concentric and eccentric + core + mechanics + lower body stability) (IRR = 0.50 [95%CI = 0.35 to 0.71]) was more effective than control group (figure 3d). Supplementary file 5 presents the network meta-analysis estimates for the 21 possible pair-wise comparisons between programs.

3.3.1.5. Ankle injuries

All six IPPs included in the network meta-analysis (figure 2e) were directly compared with the control group in the 11 primary studies included (2,3,31–33,35,37,39,40,45,46), while only indirect evidence was available for comparisons between the remaining programs. Four out of the six IPPs that were incorporated into the network meta-analysis were more effective than the control group in reducing ankle IIRs (IPPs numbered with 3 [upper body pushing and pulling + lower body concentric and eccentric + core + mechanics + lower body stability], 6 [lower body concentric and eccentric + core + mechanics], 9 [upper body pushing and pulling + lower body concentric and eccentric + lower body stability], and 10 [core]), being the number 10 (core) the one with the lowest IRR (0.14 [95%CI =

0.04 to 0.47]) (figure 3e). Supplementary file 5 presents the network meta-analysis estimates for the 21 possible pair-wise comparisons between programs.

3.3.2. Individual effects of components by movement patterns

As shown in Figure 4, the network meta-analysis at the component level revealed that only the lower body concentric and eccentric movement pattern was associated with a significant injury risk mitigation effect on overall injuries (IRR = 0.34 [95%CI = 0.19 to 0.59]). Although the pooled estimates of both lower body stability and upper body pushing and pulling were 0.87, respectively, the CIs for these components included the value 1, and thus, their potential association with a further reduction in the risk of overall injuries is inconclusive. The lack of data prevented us from calculating pooled estimates at the component level for the remaining injury types.

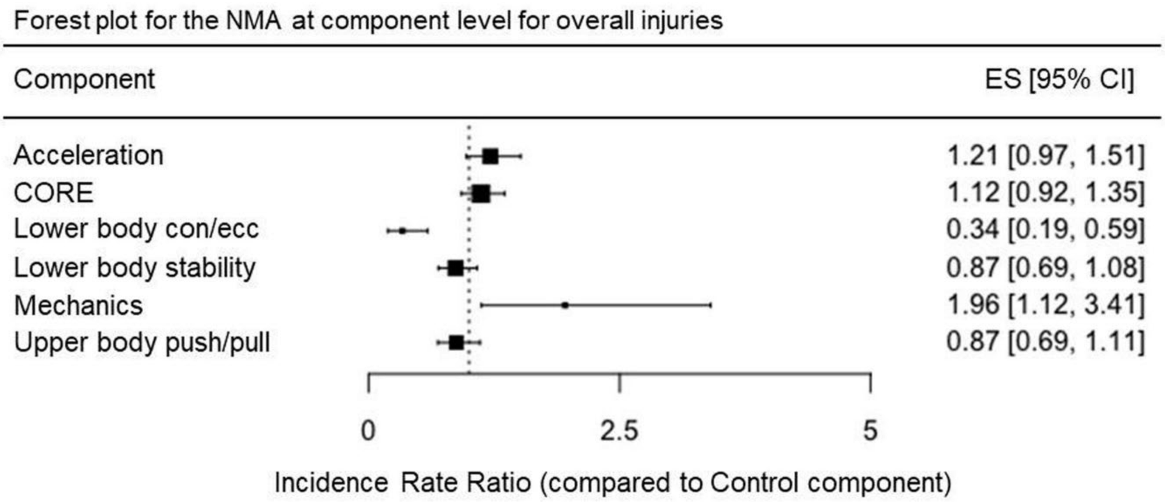

Figure 4Forest plots for the random-effects network meta-analyses at component level conducted for overall injuries.

Legend: con/ecc: concentric and eccentric; push/pull: pushing and pulling. Values below 1 favor the training component over the control.

4. DISCUSSION

Epidemiological studies (9,47,48) emphasize the urgent need to implement strategies aimed at mitigating the risk of injury in youth intermittent team sports, not only based on their documented high incidence rates (2.9-26.7 injuries per 1000 hours of exposure (47,48)) but also due to the significant increase noticed in recent years in the number of diagnosed severe injuries (e.g., ACL ruptures) (49,50), whose consequences (both in the short, medium and long-term) on youth athletes' health status, well-being and sports development might be devastating. As shown in Part 1 (1), regular implementation of exercise-based strategies (i.e., IPPs) has been demonstrated to have a high effectiveness in reducing the number of injuries sustained by youth team sport athletes. However, meta-analytical studies (including the one presented in Part 1) have reported the existence of high heterogeneity in the magnitude of the pooled prophylactic effects of IPPs, making it difficult to make evidence-based best-practice guidelines for designing effective IPPs (1,4–7). It has been suggested that the content of the IPPs may be a predictive factor (albeit not the only one) of the efficacy of these ones. Therefore, in this Part 2 of the study, a network meta-analysis was conducted a) to estimate and compare the pooled effects of some IPPs whose exercise-based components were categorized using a movement pattern-specific taxonomy on reducing overall and some specific body regions (lower extremity, thigh, knee, and ankle) injury incidences in youth team sport athletes as well as b) to explore the individual effects of these components. To address these objectives, data extracted from the 19 studies finally included in the systematic review carried out in Part 2 of this manuscript were analyzed according to two different levels of concretion. Next, the main findings obtained from these two levels of analysis are presented and discussed separately.

4.1 Multiple comparisons between the injury risk mitigation pooled effects of the different IPPs and with the control group

The findings of this second part inform that most of the IPPs exhibit either statistically significant effects or values close to being statistically significant (according to their upper 95% confidence intervals [CI] that are approaching the value of 1) injury risk mitigation effects (overall, lower extremity and ankle injuries) when compared to their respective control groups (figure 3a, 3b and 3e). However, it is important to note that only the effectiveness of IPPs number 2 (lower body concentric and eccentric + core + mechanics + acceleration + lower body stability [this includes FIFA 11+]), 3 (upper body pushing and pulling + lower body concentric and eccentric + core + mechanics + lower body stability [this includes FIFA 11+ Kids]) and 5 (lower body concentric and eccentric + core + mechanics + lower body stability) in reducing overall, lower extremity and ankle injuries have been assessed across two or more different studies encompassing large samples of youth team sport athletes (IPP 2 = 7 studies and 7258 participants, IPP 3 = 3 studies and 5597 participants, IPP 5 = 2 studies and 1023 participants). Therefore, based on the current evidence it might be reasonably affirmed that IPPs numbered 2, 3, and 5 have proven positive effects in reducing the IIRs in intermittent team sports (mainly soccer). Conversely, further research is warranted to assess other IPPs' effectiveness and deepen our understanding of their potential prophylactic effects against injuries. The paired comparisons carried out among these three IPPs with the control group revealed that program 3 was the most effective in reducing overall, lower extremity, and ankle IIRs in youth athletes. Likewise, the network meta-analyses also showed a significant superior effect of program 3 against program 2 for overall and lower extremity injuries, while no statistically significant differences between the pooled effects of IPPs numbered 2 and 5 were reported (see supplementary file 5). However, it should be pointed out that the potential injury risk mitigation effects of IPPs 2 and 5 were consistently explored in studies involving participants who displayed a chronological age ranging from 12 to 18 years old (adolescents) (2,31,32,34,39,41,42,44,46) whereas the trials using IPP number 3 always recruited athletes below the age of (or equal to) 12 years (children) (3,35,37). Consequently, the implementation of IPP number 3 (upper body pushing and pulling + lower body concentric and eccentric + core + mechanics + lower body stability) could be recommended in sporting contexts where the players are children (ages between 8 and 12 years [pre-peak height velocity]), not only because of its documented effectiveness but also due to the fact that the exercises have been specifically selected by considering their psychological and affective needs as well as motor competence. In contrast, the implementation of IPPs numbered 2 and 5 could be effective measures to reduce the number of injuries in adolescent athletes and those adults whose training age ranges between 4 and 8 years. IPPs 2, 3, and 5 share four common exercise components (lower body concentric and eccentric + core + mechanics + lower body stability) and differ in one of them (only between IPPs 2 and 3 where the acceleration and upper body pushing and pulling components are exchanged). Therefore, the limited scientific evidence accumulated does not allow ascertaining whether a combination of exercise components based on movement patterns should be incorporated into IPPs to maximize their effects of mitigating the risk of injury (overall, lower extremity, and of the ankle joint) in youth team sports athletes. However, it could be suggested that any IPP aimed at reducing the risk of injury in youth team sports athletes should include exercises targeted to the following components: lower body concentric and eccentric, core (anti-rotation and core bracing), mechanics (change of direction [COD], jumping and landing, and rebounding), and lower body stability.

The results of this network meta-analysis also indicate that none of the IPPs defined according to the movement pattern-specific taxonomy suggested by Moody et al. (22) and included in this sub-analysis (IPPs numbered 2, 3, 5, 6, 9, and 10) has proven to be an effective exercise-based strategy for reducing the risk of suffering thigh injuries in youth team sport athletes. Recent epidemiological data have reported that the most prevalent thigh injuries in youth team sport athletes are muscle strains, particularly those occurring in the hamstring, adductor, and quadriceps muscles, with figures close to 65% of the total injuries recorded in this anatomical region (8,51). From a biomechanical model of injury causation standpoint, muscle injury is considered the result of applied mechanical load exceeding the tissue capacity to withstand strain (52). Per se, a complex interaction between internal and external factors influencing tissue strain or strain capacity is required for injury to occur (52). In intermittent team sports, thigh muscle strains (i.e., hamstring, quadriceps, and adductor) usually occur by an indirect mechanism and during rapid movements with high eccentric demands (53). According to this injury indirect mechanism, hamstring, quadriceps, and adductor muscle strains might be classified as follows: sprint type (mainly hamstring and quadriceps), stretch type (hamstring, adductor, and quadriceps), and mixed type (hamstring and quadriceps) (15,54–56). While most of the sprint-related hamstring and quadriceps injuries occur during lineal sprint acceleration (hamstring) and deceleration (quadriceps) and high-to-maximal velocity running (hamstring), the stretch-related thigh muscle injuries are connected with closed chain movements like braking or stopping and open chain movements like kicking (15). Almost all IPPs included in this network meta-analysis incorporate as part of their lower body components eccentric closed chain strength exercises that are recommended to be performed at a slow speed with a special focus on maintaining proper movement technique, such as bodyweight squats, Nordic hamstring, and walking lunges. These general or basic (i.e., they do not replicate the fast and multiplanar nature of most of the team sport-related actions) eccentric strength exercises may provide some benefit in developing thigh muscles' capacity to withstand strain. Likewise, four out of the six IPPs (numbered as 2, 3, 5, and 6) included in this sub-analysis also incorporate a few exercises that target jump and change of direction mechanics such as multidirectional single- and double-leg jumps, ice-skater jumps, and planned planting and cutting tasks. These more sport-contextualized exercises are to some extent representative (from a movement-centered perspective) of the stretch-type injury-inciting events and may assist in improving thigh muscle mechanical robustness or function (i.e., applied capacity) (57). However, it is important to highlight that only IPP number 2 includes the acceleration component, which might help to improve the thigh muscles' robustness to manage the high mechanical loading conditions generated during those locomotive tasks identified as inciting events for sprint-related hamstring and quadriceps muscle injuries. It is worth noting that according to some review articles, which propose some general guidelines for eccentric strength development (58), the exercise dose within both the mechanics and acceleration components of the IPPs included in this sub-analysis may be insufficient to produce significant improvements in the applied element (i.e., function) of the mechanical capacity of the thigh muscles. Furthermore, in contrast to the fundamental strength exercises commonly integrated into the lower body component of IPPs, the rapid locomotive actions within the mechanics and acceleration components lack a graduated approach in difficulty levels. Consequently, it is plausible that these actions may be perceived as undemanding in terms of complexity and intensity (resulting in null protective effects) for certain athletes, while others may perceive them as quite the opposite (resulting in risk exacerbation effects). Therefore, a compelling argument that may partially explain the ineffectiveness of IPPs in mitigating thigh injuries (hamstring, quadriceps, and adductor muscle tears) could lie in the omission or inadequate dosage of exercises aimed at improving progressively the ability of youth athletes to perform sudden horizontal acceleration and deceleration, high-speed running, and explosive change of direction after braking actions and to skillfully manage their subsequent high impact peaks and loading rates even though these are their most frequent inciting events.

Finally, regarding knee injuries, this study presents contradictory results (figure 3d). In this sense, one IPP (number 3) demonstrates statistically significant prophylactic effects. Two other IPPs (numbers 2 and 6) show risk mitigation effects on injuries that are approaching statistical significance. However, three IPPs (numbers 5, 9, and 10) do not exhibit meaningful effects on the number of injuries sustained by participants in the experimental group compared to their counterparts in the control group. When the contents of these six IPPs are analyzed in depth it cannot be concluded that the movement pattern-specific taxonomy suggested elsewhere to categorize the different exercises does provide strong arguments to explain this observed discrepancy in injury risk mitigation effects, as many of them include the same components and combinations of them. The only noteworthy aspect may be the observation that program 5, despite containing almost identical components (including lower body concentric and eccentric, core, mechanics, and lower body stability) to program 3, which demonstrates significant effects, fails to yield meaningful effects. The sole difference between these two IPPs lies in the absence of upper body pushing and pulling exercises in program 5. Previous research (59) has found that upper body fatigue may negatively impact lower extremity neuromuscular control. This leads to the hypothesis that distant fatigue, defined as fatigue affecting muscle groups dissociated from the primary movement of joints involved in one’s base of support, could contribute to increase injury risk among athletes (59). The results obtained by programs number 3 and 5 for ankle injuries further support this assumption. These findings suggest a potential benefit from the inclusion of upper body exercises for reducing injuries in both knee and ankle joints, which underscores the interconnectedness of various muscle groups and the importance of holistic training approaches in injury prevention strategies. On the other hand, a visual inspection of the forest plot presented in Figure 3d reveals that two of these three IPPs whose pooled effects were calculated using multiple estimations (IPP 2 = 4 studies; IPP 3 = 3 studies) and extensive cohorts of athletes (> 4000 participants) were the ones that showed statistically significant or close-to-significant knee injury risk mitigation effects. Therefore, although speculative, there seems to be a directly proportional relationship between the robustness of the pooled effects of IPPs and their effectiveness in reducing the risk of knee injuries in youth athletes.

4.2 Individual effects of exercise-based components

The main findings from this deepest level of the analysis reveal that the exercise-based component lower body (bilateral and unilateral, concentric, and eccentric) was the only one to exhibit statistically significant injury risk mitigation effects on overall IIRs (IRR = 0.34 [95% CI = 0.19 to 0.59]). This result was expected because almost all the exercises included in this component were the same as those integrated into the strength component of the network meta-analysis carried out in Part 1 and consequently, similar results were predictable.

A significant proportion of severe injuries occurring in the knee (e.g., ACL tears) and ankle (e.g., lateral ankle ligament sprains) joints involve multi-planar events, where tensile forces surpass their dynamic stabilization capacity (10–12,60). This often leads athletes to adopt aberrant movement strategies, such as knee valgus collapse (i.e., a movement in the frontal plane with a rotational component). Therefore, the lower body stability component may be considered a priori a critical aspect of any IPP aimed at reducing severe (mainly ligament) injuries. Surprisingly, the pooled prophylactic effects against overall injuries in team sports from the lower body stability component were not statistically significant (figure 4). However, it is important to note that its pooled effects approached statistical significance (pooled effect = 0.87 [95% CI = 0.69 to 1.08]). The lack of data prevented us from exploring the individual risk mitigation effects of this component separately by body regions. Thus, it is currently unknown whether the lower body stability component itself may elicit meaningful effects to reduce the number of knee and ankle injuries in this population cohort.

The findings of this third level of analysis also indicate that the acceleration (IRR = 1.21 [95% CI = 0.97 to 1.51]) and mechanics (IRR = 1.96 [95% CI = 1.12 to 3.41]) components not only fail to reduce the risk of injury but also appear to increase it. These results align with those found in Part 1 for the speed/agility and plyometric components, where once again, the exercises included in these components are nearly identical. Therefore, the same rationale provided in Part 1 to explain the heightened injury risk effects for the speed/agility and plyometric components could be applied here to the acceleration and mechanics components.

4.3 Limitations

In addition to the limitations indicated in Part 1 and which are also shared by this Part 2 (e.g., only indirect evidence available for comparisons between interventions other than the control group, the order of appearance of every single component in IPPs was not considered, impossibility of studying the effects of IPPs on injury burden and for specific age subgroups, most of the studies conducted in soccer players, etc.), the current study has two specific limitations that should be noted. On the one hand, the movement pattern-specific taxonomy used for this analysis was based on previous literature (22). However, after piloting all the different elements presented in this original research for exercise categorization, we realized that we were unable to precisely identify some of them (e.g., lower body unilateral concentric and eccentric) for certain interventions due to poor reporting of primary studies (some of them only presented a few examples of exercises, without including a detailed description of all the exercises implemented). Therefore, after a discussion within our team, we decided to unify some categories (e.g., lower body bilateral [concentric and eccentric] and lower body unilateral [concentric and eccentric] exercises) and to create a new category that would include common exercises used in prevention programs and that were not collected under the original proposal (i.e., lower body stability). Consequently, we had to make slight adaptations to the classification proposed by Moody et al. (22), preventing some comparisons between fundamental movement patterns (e.g., lower body unilateral vs. bilateral). On the other hand, the network meta-analysis at the component level was only conducted in this study for overall injuries due to limited data. As mentioned previously, this prevented us from studying whether the incidence of knee and ankle injuries can be significantly reduced by the implementation of lower-body stability exercises. The lack of data also did not allow us to analyze the influence of these interventions on the reduction of growth-related injuries.

5. CONCLUSIONS

Most of the IPPs analyzed in this study demonstrated a reduction in the incidence of overall, lower extremity, and ankle injuries compared to their respective control groups. A combination of lower body concentric and eccentric exercises, along with core exercises (anti-rotation and core bracing), mechanics exercises (change of direction [COD], jumping and landing, and rebounding), and lower body stability exercises, appeared to be necessary to minimize these injuries in youth. However, the existing evidence is limited to three main programs (numbers 2, 3, 5) evaluated in more than a single trial. Further studies investigating other promising interventions, such as those combining upper-body pushing and pulling exercises with lower-body concentric and eccentric exercises and lower-body stability exercises, are warranted. Finally, the lack of effectiveness of interventions in reducing thigh injuries underscores the need for reconsideration of prevention strategies targeting this injury location.

When compared to the taxonomy focused on classical training components used in Part 1, categorizing the components of IPPs based on the movement patterns of their exercises may, a priori, be considered a criterion more closely associated with the injury phenomenon (especially with its most frequent mechanisms of occurrence). Consequently, the movement-pattern taxonomy used in this Part 2 was envisioned as a potential measure to elucidate the considerable heterogeneity previously observed in the pooled effects of the IPPs. However, from a practical perspective, the findings of this study demonstrate that using a movement pattern taxonomy to group IPP exercises does not provide additional insights compared to the classical approach on this issue. The main reason justifying this claim is based on the fact that some of the components defined by both taxonomies incorporate almost the same exercises, and consequently, their potential effects are identical. Future studies employing different methods to categorize IPP exercises, such as the task-specific taxonomy proposed by Dischiavi et al. (61) (considering factors like plane of movement [sagittal plane, transverse plane, frontal plane, and multiplanar], weight-bearing status [unilateral, bilateral, and non-weight-bearing], trunk and hip dissociative control, and flight phase), may offer insights into the essential components that should be integrated into an IPP to optimize its effectiveness in mitigating risks in youth team sports.

AUTHORS' CONTRIBUTIONS

FA, FJR-P, and MDSC conceived and designed the research; FA, FJR-P, DB-R, AL-V, JALL, and MDSC analyzed and interpreted the data; FA, FJR-P, and DB-R led the drafting of the manuscript; AL-V, JALL, and MDSC revised the manuscript critically for important intellectual content. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

DISCLOSURE STATEMENT

The authors report no conflict of interest.

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DATA AVAILABILITY STATEMENT

R codes are publicly available on https://data.mendeley.com/datasets/hg4m522fc5/1. Additional data may be accessed upon reasonable request.

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TABLES

Table 1. Component breakdown of injury prevention programs according to specific movement patterns.

Table 2. Results of the network meta-analysis for overall injuries: Estimates and 95% confidence intervals for comparisons between each pair of injury prevention programs (programs in rows vs. programs in columns).

SUPPLEMENTARY FILES

Supplementary file 1. PRISMA NMA checklist of items to include when reporting a systematic review involving a network meta-analysis.

Supplementary file 2. Inclusion/exclusion criteria for young team-sport players' injuries literature search.

Supplementary file 3. Search strategy.

Supplementary file 4. Moderator variables coded.

Supplementary file 5. Results of the network meta-analysis for lower extremity injuries, thigh, knee, and ankle injuries.