The Efficacy of Injury Prevention Programs in Adolescent Team Sports: A Meta-analysis

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Team Physician's Corner

The Efficacy of Injury Prevention Programs in Adolescent Team Sports

A Meta-analysis

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Background: Intensive sport participation in childhood and adolescence is an established cause of acute and overuse injury. Interventions and programs designed to prevent such injuries are important in reducing individual and societal costs associated with treatment and recovery. Likewise, they help to maintain the accrual of positive outcomes from participation, such as cardiovascular health and skill development. To date, several studies have individually tested the effectiveness of injury prevention programs (IPPs).

Purpose: To determine the overall efficacy of structured multifaceted IPPs containing a combination of warm-up, neuromuscular strength, or proprioception training, targeting injury reduction rates according to risk exposure time in adolescent team sport contexts.

Study Design: Systematic review and meta-analysis.

Methods: With established inclusion criteria, studies were searched in the following databases: Cochrane Central Register of Controlled Trials, MEDLINE, SPORTDiscus, Web of Science, EMBASE, CINAHL, and AusSportMed. The keyword search terms (including derivations) included the following: adolescents, sports, athletic injuries, prevention/warm-up programs. Eligible studies were then pooled for meta-analysis with an invariance random-effects model, with injury rate ratio (IRR) as the primary outcome. Heterogeneity among studies and publication bias were tested, and subgroup analysis examined heterogeneity sources.

Results: Across 10 studies, including 9 randomized controlled trials, a pooled overall point estimate yielded an IRR of 0.60 (95% CI = 0.48-0.75; a 40% reduction) while accounting for hours of risk exposure. Publication bias assessment suggested an 8% reduction in the estimate (IRR = 0.68, 95% CI = 0.54-0.84), and the prediction interval intimated that any study estimate could still fall between 0.33 and 1.48. Subgroup analyses identified no significant moderators, although possible influences may have been masked because of data constraints.

Conclusion: Compared with normative practices or control, IPPs significantly reduced IRRs in adolescent team sport contexts. The underlying explanations for IPP efficacy remain to be accurately identified, although they potentially relate to IPP content and improvements in muscular strength, proprioceptive balance, and flexibility.

Clinical Relevance: Clinical practitioners (eg, orthopaedics, physical therapists) and sports practitioners (eg, strength and conditioners, coaches) can respectively recommend and implement IPPs similar to those examined to help reduce injury rates in adolescent team sports contexts.

Keywords: injury prevention programs; injury reduction rates; youth and adolescence; team sports

In recent years, the progressive increase in intensity of sport competition and specialization from a young age brings with it both proposed benefits and problems.[37] A benefit includes the provision of opportunities to participate intensively, but this is counterbalanced by the problems of a lack of physical preparedness,[42] overexposure,[23] overtraining,[15] and an increased risk of injury.[12] Sport participation is already well established as a major cause of pain and injury in children and adolescents,[8,10] with >50% classified as overuse injuries in nature.[3,42] Such injuries also have numerous individual, social, and economic consequences, including extensive periods of nonparticipation and immobility, as well as treatment (possibly surgery for some injuries) and rehabilitation (eg, physical therapy) costs. In the longer term, this may extend to predispositions

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of recurring injuries, earlier sport termination or dropout,[5] and potentially compromised physical and psychological health.[42] With these concerns in mind, identifying methods that can either reduce the risk of sporting injury or better control and prevent overexposure is logically significant. Therefore, preventative measures aimed at injury risk reduction should be able to help maintain mobility, participation, and the accrual of positive sporting outcomes (eg, cardiovascular health, skill development) while reducing the individual, economic, and social costs from immobility, treatment, and rehabilitation.

While there is abundant literature reporting injury prevalence and the treatment of such injuries, along with a growing literature in adult sporting injury prevention, fewer investigations have examined whether interventions can prevent injury among youth players and in the relatively early stages of sport participation. To date, several randomized controlled trials (RCTs) have indicated a positive effect of injury prevention programs (IPPs) on subsequent injury rates[9,22,33,39] and performance.[40] For instance, a Federation International Football Association (FIFA) 11+ warm-up program was shown to reduce the overall injury rate by >30% in adolescent female soccer players,[39] and the Harmoknee IPP was successful in reducing knee injuries among adolescent male soccer players by 77%.[24] That said, Gatterer et al[17] cautioned that the benefit of such programs may not be universal, with possibly greater benefits for lower-skilled than intermediate or elite players. Others have proposed that as age and skill level increase, there is possibly little or no benefit from warm-up programs.[25,44] Thus, warm-up programs for participants at young ages (ie, adolescent and below) and of relatively lower skill level may have the most potential in terms of injury reduction.

In prior reviews, Hubscher et al[21] analyzed several RCTs across young and adult athletes (ie, aged 12-24 years). Their pooled findings suggested that proprioceptive and neuromuscular IPPs were effective in reducing lower limb injury risk by 39% (relative risk [RR] = 0.61, 95% CI = 0.49-0.77). Lauersen et al[26] also recently conducted a meta-analysis on 25 studies that included different IPP variations across adult (n = 14 studies) and adolescent (n = 11) samples. Analysis across their pooled studies (ie, no separation for adolescents) revealed a 68% (RR = 0.31, 95% CI = 0.21-0.48) reduction on injury rates when proprioceptive exercises were used and a 45% reduction (RR = 0.55, 95% CI = 0.35-0.87) when a combination of strength, stretching, and proprioceptive exercises was used. Similarly, Leppanen et al[27] showed that warm-up–based IPPs reduced injuries by 36% (OR = 0.64, 95% CI = 0.49-0.83). However in these analyses, the exposure hours of participants were not considered and yet is a likely influential factor in estimations. For instance, the intervention groups may have had fewer injuries but may have also played fewer matches or had fewer training sessions. Thus, expressing injuries as rates per exposure hours provides a better representation of the efficacy of IPPs. This method was used by Gagnier et al[16] in their assessment of injury prevention interventions for reducing anterior cruciate ligament (ACL) injuries.

To add, within the last few years, more RCT studies have been published,[9,28,34] and these also report and account for exposure hours of adolescent athletes. With these data emerging, combined with the concerns for accurately accounting for exposure hours and the need to focus on adolescent and the most vulnerable populations, the purpose of this study was to determine the efficacy of IPPs as compared with normative practices using data synthesis meta-analytic procedures. Analysis focused on studies that contained IPPs with a warm-up, neuromuscular strength, and/or proprioception training. Interventions also had to target injury reduction rates in adolescent team sport contexts. The moderating effects of participant (eg, sex, study compliance), context (eg, sport type), and injury intervention program variables and characteristics (eg, program type, content, and duration) on injury risk reduction were also assessed. These were examined to inform the development and implementation of efficacious IPPs in adolescent team sport contexts if such programs were found to reduce sporting injuries rates.

METHODS

Definition of Injury

Injury was defined in accordance with Fuller et al,[13] who stated that an injury can be registered if it causes the player to be unable to fully take part in the next match or training session (ie, time loss). Injuries that caused the player to seek medical attention while playing the sport were also included (ie, non–time loss).[9,11] Thus, all types of injuries that fitted these definitions were included.

Criteria for Selecting Studies

Injury Prevention Programs. IPPs were defined as structured multifaceted interventions that could contain forms of warm-up, stretching, neuromuscular, agility, strength/conditioning, or proprioceptive training activity that had the aim of reducing injury. IPPs in identified studies were partially or completely implemented on the playing field preceding training and competitive matches conducted as part of or across the regular season. IPPs had consistent and regular contact with participants and had at least 15 minutes of treatment exposure per contact session. The number of exposure hours reported included both training session and competition (match) time.

Types of Research Design. Studies that were intervention-based (cluster) RCTs, prospective cohort studies, or observational studies were included. Studies that was published in English, in any year, in print or online were accepted. Comparison (control) groups had to contain similar-age participants who were also sport active but received a sham or no form of IPP but still were exposed to normative existing practices.

Types of Participants. Studies were included if they investigated adolescents and teenage participants (average age range, 11-20 years) who were engaged in organized team sports at various levels of participation.

Outcome Measures. The primary outcome measures of interest were the total number, rate, and/or ratio of injuries and the total exposure hours. The type, nature, and location of injury were not of primary interest.

Search Methods for Study Identification

Using Cochrane handbook[20] search guidelines, 2 researchers (N.S. and J.F.) independently searched for eligible studies from July to November 2014 using the following databases: the Cochrane Central Register of Controlled Trials, MEDLINE, SPORTDiscus, Web of Science, EMBASE, CINAHL, and AusSportMed. The electronic searches were conducted with word strings that covered the relevant study designs (eg, RCTs) combined with subject-specific (ie, types of IPP) and sport context search terms. Four main criteria were applied during the search (ie, age, sport, injury, injury prevention/warm-up programs). The 10 most-participated team sports in the world[32] were included as sport context terms. Thus, the main keywords were as follows: youth* OR adolescent* OR child* OR school age OR teenage* AND sport* OR soccer OR football OR basketball OR cricket OR rugby OR ice-hockey OR field-hockey OR hockey OR volleyball OR baseball OR American Football AND athletic injury* OR sports injury* OR injuries AND injury prevention program* OR warm-up* OR exercise* OR strength* OR conditioning OR prevention OR preparation.

Appendix A (available online at http://ajsm.sagepub.com/supplemental) lists the detailed keywords and their variations used.

Data Collation and Extraction

Inclusion Procedure. The study-screening process adhered to PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) recommendations.[31] After duplicates were removed from the independent searches, articles were excluded per the identified criteria for study selection. Figure 1 summarizes the systematic steps involved in study screening. Once a preliminary list of studies was identified, reference lists of studies and other related review articles were searched for potential additional studies. Where any ambiguity existed regarding study relevancy, this was discussed and a consensus decision reached. From 3962 studies initially identified, 10 clearly met inclusion criteria and were taken forward for meta-analysis. Appendix B (available online) shows the search results and the number of studies extracted from research databases.

Data Extraction. Background information was extracted pertaining to study title, author names, publication, source, year, research design, as well as inclusion and exclusion criteria. In terms of study characteristics, sample data were recorded as they related to intervention and control groups, including the number of participants, sex, age, team sport type, and level or standard of sport participation. For characteristics associated with intervention and control groups, information was extracted where possible as related to IPP type, content, timing, nature of implementation (ie, number of warm-up, training sessions, frequency, dose, duration), and compliance (ie, percentage, sessions attended) (Table 1). The outcome measures extracted included the total number of injuries, exposure hours (training and match), as well as injury risk or rate ratios. Results were also extracted for the estimates of the intervention effect with variance estimates and 95% confidence limits or P values for null hypothesis testing. Appendix C (available online) summarizes the data extracted in tabular form.

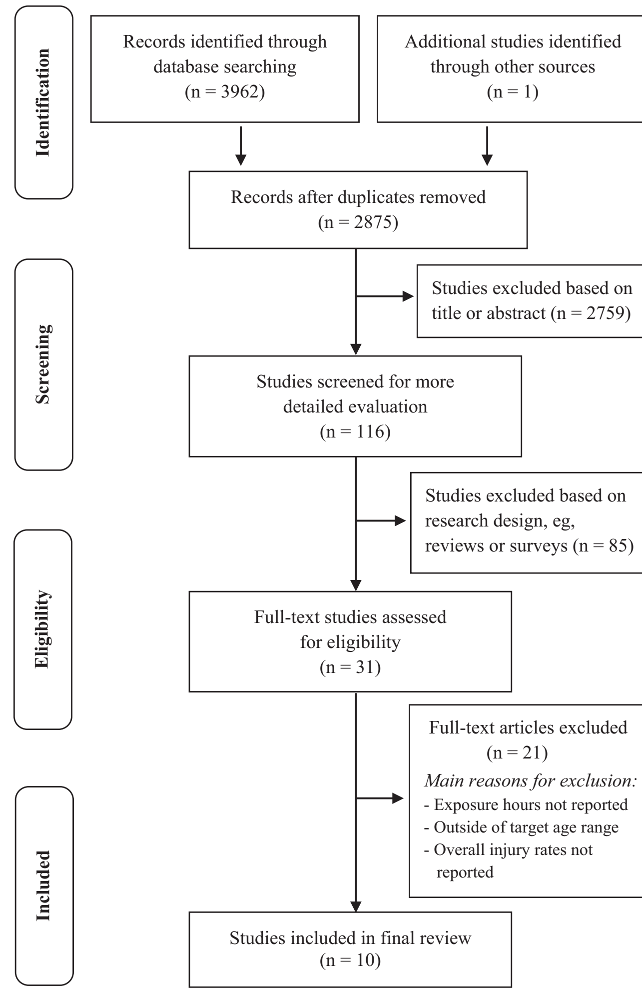

Figure 1. Flow diagram for screening and selection of studies according to PRISMA.

Data Analysis

Identified Studies: Methodological Quality. Two researchers (N.S. and S.E.) independently scored methodological quality using 12 quality criteria adapted from Furlan et al[14] (see online Appendix D). The risk of bias was assessed by allocating a score against items related to, for example, study design, blinding of participants, and compliance. All items were scored as follows: + = yes (1 point), – = no (0 points), ? = don't know (0 points). Individual study scores are summarized in Table 2. Studies were considered "high quality" if they scored $\geq$60% of the maximum score. If reviewers were uncertain of scoring on a particular criterion, owing to insufficient information in reporting, attempts to

TABLE 1
Characteristics and Content of Identified Studies[a]

				Type of Warm-up					
Study	Sex	Level	Sport	Intervention Group	Control Group	Sessions	Duration, mo	Compliance, %	Quality Score
Wedderkopp et al[46] 1999	F	Club	Handball	Ankle disk balance 10-15 min + functional strength training >2 exercises different muscle groups	As usual	No data	10	No data	7
Junge et al[22] 2002	M	Amateur	Soccer	FIFA-MARC Bricks[b]	As usual	No data	12	No data	5
Wedderkopp et al[45] 2003	F	Club	Handball	Ankle disk balance 10-15 min + functional strength training >2 exercises different muscle groups.	Functional strength training >2 exercises different muscle groups	No data	9	No data	5
Olsen et al[33] 2005	Mix[c]	Club	Handball	Balance, strength, running, and technique exercises, 15-20 min	As usual	All sessions first month, then 1/wk	8	87	9
Emery et al[11] 2007	Mix[d]	Amateur	Basketball	Ae, St, Dy stretches 10 min + sports-specific balance warm-up 5 min + home wobble board exercise up to 20 min/wk	Ae, St, Dy stretches 10 min	5/wk	12	73	9
Soligard et al[39] 2008	F	Club	Soccer	FIFA 11+ 20 min	As usual	2/wk	8	77	8
Steffen et al[41] 2008	F	Club	Soccer	FIFA 11+ 20 min	As usual	All sessions first month, then 1/wk	6	52	9
Emery and Meeuwisse[9] 2010	Mix[e]	Mix (1-2 tier)	Soccer	Ae, St, Dy stretches 5 min strength / agility 10 min + home wobble board exercise up to 20 min/wk	Ae, St, Dy stretches 15 min	Nil	4.5	81.25	9
Longo et al[28] 2012	M	Elite	Basketball	FIFA 11+ 20 min	As usual	Sessions, 3/wk	9	100	8
Owoeye et al[34] 2014	M	Club	Soccer	FIFA 11+ 20 min	As usual	Sessions, 2/wk	6	60	7

[a]Ae, aerobic exercise; Dy, dynamic; F, female; M, male; St, static.
[b]Bricks is an older version of FIFA 11+ warm-up program.
[c]Females, n = 1586; males, n = 251.
[d]Females, n = 456; males, n = 464.
[e]Females, n = 161; males, n = 219.

contact authors were made. If ambiguity or disagreement remained, authors R.S. and S.C. were consulted. All 10 studies scored at least 5 of 12 on the scale, with 6 rated as "high quality." Failure to blind intervention group participants and researchers (who recorded injury events) was a common methodological weakness noted.

Meta-analysis. All study and outcome data were transferred and analyzed with Comprehensive Meta-Analysis software (Biostat 2005). The injury rate ratio (IRR) for each study was calculated as follows: IRR = (injury rate in intervention group / hours of total exposure) / (injury rate in control group / hours of total exposure). This means, for example, that an IRR of 0.80 equated to a 20% reduction of injuries in favor of the intervention. These figures, along with log IRRs, standard errors, and variance, were used for data analysis. An invariance random-effects model was applied, with the assumption that studies drew on divergent populations and contexts, included possibly different research designs, and tested different IPPs. Thus, a true exact effect size was not expected to exist across studies.

The overall IRR point estimate and confidence intervals indicated the pooled overall effect, while the Z and P values tested the null hypothesis that the IRR estimate was no more effective than control. A prediction interval was calculated to estimate how widely the effect size may vary from study to study. The Q statistic (with df and P value) was scrutinized to provide a test of the null hypothesis that all studies shared a common effect size. If all studies shared a similar effect size, the Q value would be approximately equal to the degrees of freedom. The I^2 statistic identified the proportion of the observed variance reflecting differences in true effect sizes as opposed to sampling error. Moderate to high values ($\geq$0.50) were used to suggest potential value in subgroup analysis to explain heterogeneity sources. T^2 provided the estimate of between-study variance in true effects, and T provided the estimate of the between-study standard deviation in true effects.

Publication Bias. Standard funnel plots were used to detect signs of publication bias. The Egger test[7] was then applied to confirm asymmetry, and "trim and fill"[6]

TABLE 2
Study Quality and Risk of Bias Assessment[a]

	Study									
Quality Item	Wedderkopp et al[46] 1999	Junge et al[22] 2002	Wedderkopp et al[45] 2003	Olsen et al[33] 2005	Emery et al[11] 2007	Soligard et al[39] 2008	Steffen et al[41] 2008	Emery and Meeuwisse[9] 2010	Longo et al[28] 2012	Owoeye et al[34] 2014
Adequate randomization?	–	–	+	+	+	–	+	+	+	+
Allocation concealment?	+	–	?	+	–	+	+	+	+	–
Blinding patients?	–	–	?	–	+	–	–	+	–	–
Blinding caregiver?	–	–	?	–	?	?	–	–	–	–
Blinding outcome assessors?	–	–	–	+	+	+	+	+	–	–
Incomplete outcome data addressed? Dropouts?	+	+	–	+	+	+	+	+	+	+
Incomplete outcome data? ITT analysis?	+	–	+	+	+	+	+	+	+	+
Free of suggestions of selective outcome reporting?	+	+	+	+	+	+	+	+	+	+
Similarity baseline characteristics?	+	+	+	+	+	+	+	+	+	+
Cointerventions avoided or similar?	+	+	?	?	?	?	–	?	?	?
Compliance acceptable in all groups?	?	–	?	+	+	+	+	–	+	+
Timing of the outcome assessment similar?	+	+	+	+	+	+	+	+	+	+
Study score (of 12)	7	5	5	9	9	8	9	9	8	7
Percentage	58.3	41.6	41.6	75	75	66.6	75	75	66.6	58.3

[a]Maximum obtainable quality score, 12. +, yes (1 point); –, no (0 points); ?, don't know (0 points). ITT, intention to treat.

procedures were conducted to indicate if the overall IRR estimate required adjustments based on missing studies.

Subgroup Analysis. To examine sources of heterogeneity and identify potentially influential moderating factors on IRRs, several exploratory subgroup analyses were performed via a mixed-effect analysis and random-effects model. This assumed a common among-study variance component across subgroups. Meta-regression options were discounted owing to the limited provision of continuous data and the limited number of studies available (ie, lacking sufficient power). Subgroup analyses were considered when studies were evenly distributed (eg, use of FIFA 11+ as an IPP), when a mean value could be applied to evenly distribute studies (eg, compliance), and when $\geq$3 studies examined a given factor that could be discretely categorized (eg, sex). This meant that certain factors could not be examined, such as age, maturation status, and skill level of participants, owing to either insufficient data or reporting or an inability to discretely categorize. Identified and examinable factors led to 8 independent subgroup analyses:

1. Sex: male (3 studies) vs female (4) vs mixed (3)
2. Sport type: soccer (5) vs baseball/basketball combined (5)
3. Comparison group type: sham intervention (3) vs control or as per usual (7)
4. IPP type: FIFA 11+ (5) vs non–FIFA 11+ (5)
5. Wobble board use: no (6) vs yes (4)
6. Intervention duration: <8 months (5) vs $\geq$8 months (5)
7. Participant compliance: >70% (5) vs $\leq$70% (5)
8. Study quality: <60% (4) vs $\geq$60% (6)

The between-group *Q*, *df*, and *P* values identified whether one particular subgroup IRR (and 95% CIs) was more associated with injury reduction. Evidence of dispersion in true effects among subgroups was also scrutinized.

RESULTS

Study Characteristics

Of the 10 identified studies (9 RCTs, 1 prospective cohort design), participants in 4 were female; 3 had male participants only; and 3 had mixed-sex samples. In terms of sport type, 5 studies were in soccer, 3 in handball, and 2 in basketball. The mean duration of IPP interventions was 8 months (range, 4.5-12 months). In terms of injury reporting, 6 studies reported "time loss" injuries in which players did not participate in the next match or training session,[9,11,22,28,34,41] while the other 4 considered both time loss and non–time loss injuries. See Table 1 and Appendix C for further details on individual study characteristics.

In terms of IPP content in identified studies, 2 broad categories of program could be identified on the basis of their content: (1) FIFA 11+ warm-up program and its associated versions (5 studies) and (2) other modified and generic IPPs (5 studies). The FIFA 11+ group included studies that were based on a multifaceted IPP as

Study	Rate ratio	95% CI	Intervention (Events / Total)	Control (Events / Total)	Relative weight
Wedderkopp et al, 1999	0.255	0.143-0.455	14 / 16501	66 / 19870	7.37
Junge et al, 2002	0.791	0.592-1.058	77 / 11475	111 / 13090	11.53
Wedderkopp et al, 2003	0.373	0.146-0.953	6 / 11546	16 / 11487	4.10
Olsen et al, 2005	0.493	0.388-0.625	103 / 93812	195 / 87483	12.29
Emery et al, 2007	0.819	0.645-1.039	130 / 39369	141 / 34955	12.30
Soligard et al, 2008	0.682	0.556-0.836	161 / 49899	215 / 45428	12.77
Steffen et al, 2008	0.994	0.831-1.188	242 / 66423	241 / 65725	13.09
Emery and Meeuwisse, 2010	0.621	0.436-0.885	50 / 24051	79 / 23597	10.54
Longo et al, 2012	0.441	0.217-0.894	14 / 23640	17 / 12648	5.92
Owoeye et al, 2014	0.458	0.312-0.673	36 / 51017	94 / 61045	10.08
Overall	**0.602**	**0.481-0.754**			

Random effects model

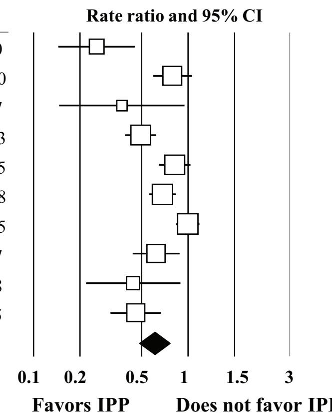

Figure 2. Forest plot illustrating the pooled effect of injury prevention programs (IPPs) as compared with controls on injury rate ratios.

recommended by FIFA and that encompassed aspects of the older F-MARC 11 and Bricks programs. FIFA IPPs typically contained 15 single exercises aimed to improve lower limb neuromuscular control, strength, and stability (ie, balance) in youth soccer players. Conducted within a 20-minute session prior to training and/or competition, these IPPs included exercises for stability (eg, "bench," "side-way-bench"), balance (eg, "single-leg stance eyes-closed"), dynamic stabilization (eg, "walking lunges," "plant and cut"), eccentric hamstrings strength (eg, Nordic hamstring exercise), and quadriceps strength (eg, box jumps, squats) alongside general running (ie, for warm-up). FIFA IPPs also had a variety of running and jumping exercises to improve agility and strength.[28,39]

The other 5 studies had alternative IPP content (ie, not akin to FIFA 11+). These often included a combination of components, such as a 5-minute general warm-up (eg, aerobic low-intensity jogging or running) and 10 minutes of static and dynamic stretching exercises combined with functional strength exercises; agility training for 10 minutes (eg, walking lunges, eccentric hamstring lunges); and/or a 10- to 20-minute home-based component of exercises using a wobble board.[9,11,33,45,46]

Meta-analysis: Injury Rate Ratios

Figure 2 provides a summary of the data entered and IRRs for each study as well as the pooled estimate. Based on identified studies[‡] sampled from a universe of possible studies, pooled data reflected 8513 predominantly adolescent participants (age range, 11-20 years) involved in 756,461 exposure hours with a total of 2008 injuries. The overall IRR of 0.60 (95% CI = 0.48-0.75) suggested a 40% reduction of injuries based on IPPs when compared with controls and accounting for exposure hours. CIs indicated that the true estimate resided within this range. The prediction interval (0.33-1.48) suggested that the true effect size for any one study could still possibly fall within such values. The null hypothesis was rejected ($Z = -7.77$, $P < .0001$), leading us to state that IPPs significantly reduce the IRR. The Q statistic of 45.75 ($df = 9$, $P < .001$) highlighted that the true effect size was not the same in all studies. The I^2 of 80.33 reflected that approximately 80% of the variance in the observed effects were due to true effects, while T^2 and T were 0.09 and 0.3 (in log units), respectively.

Publication Bias

Inspection of funnel plots suggested that bias was likely (see Figure 3). Based on identified studies, asymmetry was apparent, as smaller studies typically had higher-than-average effect sizes, with low effect sizes absent. That said, larger studies were clustered symmetrically around the mean effect size. The Egger test[7] confirmed asymmetry (intercept = −3.49, SE = 1.34, $P = .03$). The "trim and fill" procedure of Duval and Tweedie[6] provided an adjusted overall IRR of 0.68 (95% CI = 0.54-0.84; n = 3 imputed studies), indicating that a minor adjustment to the overall point estimate was warranted. The adjusted point estimate remained fairly close to the original estimate.

Subgroup Analyses

Table 3 summarizes results from the mixed-effect analyses and when a random-effects model was applied according to the 8 moderating factors entered. Although subgroups were predominantly associated with IRR reduction, Q and P values for between-subgroup comparisons indicated no discernible differences. However, ≥10% differences and movements toward significance were observed in IRR estimates when studies—relative to their reference subgroups—had handball/basketball as a context (IRR = 0.49 vs soccer = 0.70) and an IPP alternate to FIFA 11+ (IRR = 0.52 vs FIFA 11+ = 0.68). IPPs lasting >8 months (IRR = 0.54 vs <8

[‡]References 9, 11, 22, 28, 33, 34, 39, 41, 45, 46

TABLE 3
Subgroup Analyses According to Identified Moderating Factors[a]

	Mixed-Effects Analysis Between-Subgroup Comparison						Subgroup Heterogeneity		
Moderator: Subgroup (No. of Studies)[b]	Point Estimate	95% CI	*P* Value	Possible IRR Reduction, %	*Q* Value	*P* Value	*Q* Value[c]	*P* Value[d]	Subgroup I^2
Sex									
Male (3)	0.56	0.38-0.90	.001	44					66.53
Female (4)	0.58	0.38-0.87	.001	42			40.20	<.001	88.23
Mixed (3)	0.63	0.41-0.96	.003	37	0.12	0.94	5.58	.06	77.07
Sport type									
Soccer (5)	0.70	0.52-0.93	.001	30			36.69	<.001	77.36
Handball/basketball (5)	0.49	0.34-0.68	.001	51	2.50	0.11	9.07	.003	78.96
Comparison group type									
Sham intervention (3)	0.64	0.40-1.02	.06	—			45.54	<.001	85.67
Control (7)	0.58	0.43-0.77	<.001	42	0.14	0.69	0.22	.63	45.28
IPP type									
FIFA 11+ (5)	0.68	0.50-0.92	.001	32			37.16	<.001	78.51
Non–FIFA 11+ (5)	0.52	0.37-0.72	<.001	48	1.39	0.23	8.67	.003	78.42
Wobble board use									
Yes (4)	0.52	0.35-0.79	.002	48			45.13	<.001	80.09
No (6)	0.59	0.47-0.86	.003	41	0.56	0.45	0.63	.42	83.36
IPP duration									
<8 mo (5)	0.64	0.46-0.86	.005	34			45.73	<.001	77.05
>8 mo (5)	0.54	0.37-0.79	.002	46	0.33	0.56	0.02	.86	85.86
Compliance									
>70% (5)	0.57	0.41-0.81	.002	41			41.39	<.001	87.18
<70% (5)	0.61	0.44-0.85	.003	39	0.06	0.79	4.37	.03	60.70
Study quality									
<60% (4)	0.53	0.37-0.80	.001	47			39.32	<.001	60.57
>60% (6)	0.63	0.47-0.83	.002	37	0.33	0.56	6.43	.01	84.23

[a] *Q* value, dispersion of studies about the point estimate overall or within a subgroup. I^2, heterogeneity within a subgroup. IPP, injury prevention program; IRR, injury rate ratio.
[b] Random-effects model.
[c] The top value per moderator indicates *Q* value within subgroup heterogeneity; the lower *Q* value indicates between subgroup heterogeneity.
[d] The top value per moderator indicates *P* value within subgroup heterogeneity; the lower *P* value indicates between subgroup heterogeneity.

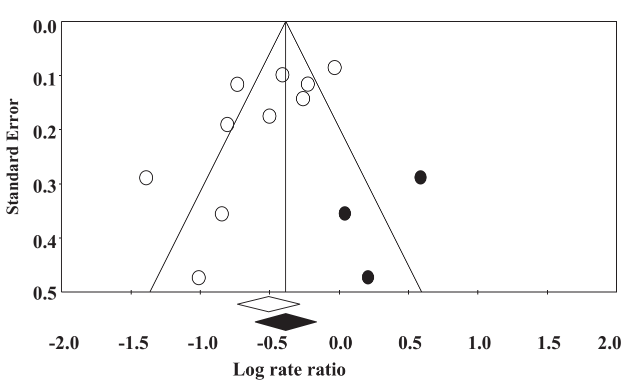

Figure 3. Funnel plot based on study standard error and log risk ratio in assessing publication bias. Nonshaded dots, observed study point estimates; shaded dots, imputed studies estimates based on the procedure by Duval and Tweedie.[6]

months = 0.64) and with lower study quality and bias assessment scores also showed ≥10% differences (IRR: <60% = 0.53 vs >60% = 0.63). Across subgroups, the total within *Q* and *P* values suggested that some true variance remained unexplained within the subgroups.

DISCUSSION

The purpose of this study was to determine the efficacy of IPPs on total injury reduction rates among adolescents in team sport contexts. When systematic search and meta-analysis procedures were applied that accounted for exposure hours, a pooled estimate of total injury risk reduction was found to be approximately 40% (pooled IRR = 0.60, 95% CI = 0.48-0.75) or 32% if adjusted for bias. This finding represents a significant and clinically meaningful reduction in injury rates. When aligned with related meta-analyses, either in different populations in terms of age and skill level or where site-specific injuries were considered, estimated reduction rates are similar. Hubscher et al[21] for example, showed a nonsignificant reduction of overall injuries when pooling 2 adolescent studies (RR = 0.49, 95% CI = 0.13-1.8, *P* = 0.28). Gagnier et al[16] showed that IPPs reduced the risk of ACL injuries by >50% (IRR = 0.48, 95% CI = 0.29-0.78, *P* = 0.003), while Lauersen et al[26] and Leppanen et al[27] identified that different types of IPPs reduced injury risk by an estimated 45% to 68%. While in alignment, present findings also add efficacy and knowledge to existing literature. This study (1) controlled for exposure hours in respective contexts; (2) examined overall injury rates, not anatomic site–specific locations; (3) focused on a subset of the population likely more exposed and vulnerable to sporting injury (ie, adolescence); (4) was based on the most current data available from high-quality research designs; and (5) had methodological procedures and study reporting quality ratings that scored highly.

Although null findings were apparent in subgroup analyses, these were likely constrained by the sample data available from individual studies (eg, sometimes <5 studies per subgroup). Both the moderating factors examined and those that could not be examined (eg, age, maturation, skill level) could still moderate IPP efficacy on IRRs. When additional data become available, these factors may be investigated. In applying a subjective criterion of a ≥10% change in IRRs among subgroups, IPPs in handball/basketball contexts (IRR = 0.49 vs soccer = 0.70) that were non–FIFA 11+ (IRR = 0.52 vs FIFA 11+ = 0.68) and that lasted for >8 months (IRR = 0.54 vs <8 months = 0.64) were highlighted as potentially being more beneficial, thereby providing some possible indication of effect moderation.

Isolating the underlying explanations of IPP efficacy generally and the potential added benefits from some factors is challenging. However, efficacy is likely associated with particular IPP components, the sport context and performance requirements, or both. In IPP terms, data and interpretations from the included studies here (alongside other associated studies) point toward benefits from lower limb muscular strength (eg, Nordic hamstring exercises, plyometric jumping), proprioceptive balance (eg, ankle disk, wobble board, balance exercises), and flexibility improvement (ie, functional dynamic stretching exercises). Both FIFA 11+ and non–FIFA 11+ IPPs contained either particular or several of these component exercises within their respective interventions. For instance, 9 of the 10 studies contained exercises targeted at lower limb muscle strength. Seven utilized Nordic hamstring exercises that have elsewhere been shown to increase eccentric hamstring strength,[30] and help prevent knee injuries (eg, ACLs).[19,33] Zein et al[47] and Pasanen et al[35] also confirmed that strength and jump time improved following use of a FIFA 11+ or similar warm-up program. Strength imbalances, such as the hamstring:quadriceps ratio, are associated with a greater likelihood of hamstring injuries,[2] and Daneshjoo et al[4] showed that 8 weeks of a FIFA 11+ IPP improved knee strength ratios.

Of the 5 studies that explicitly utilized proprioceptive lower limb balance exercises, including either an ankle disk or wobble board apparatus, 4 were also in the contexts of handball or basketball. Notably, 3 of these also reported greater reductions in IRRs[9,11,45,46] as compared with the pooled point estimate. Balance exercises in these contexts are used to help meet the performance demands that are imposed by asymmetrical, varied, and dynamic movements (ie, laterally and vertically) and that increase the risk of fall-related injuries.[43] Thus, IPPs with a combination of muscular strength as well as proprioceptive balance and stabilization exercises were likely to have been beneficial. These have been shown to be associated with improvement in the biomechanics of basic movements (eg, jumping) by reducing asymmetrical landing and abnormal ground reaction force in the knee joints.[18] Such improvements may also account for injury reduction in the upper limbs (eg, hands and fingers), as synchronous strength development (eg, jumping and moving into position) and balance stabilization (ie, at the ankle) may aid movement speed, control, and positioning and subsequently help to avoid falls. For example, Olsen et al[33] reported that finger injury rates in handball players were reduced >50%, and acute knee or ankle injuries were reduced by approximately 40%, with their IPP incorporating both strength- and balance-based exercises. Similarly, the IPP implemented by Wedderkopp et al[45,46] included balance and plyometric exercises and likewise reduced upper limb injury rates.

IPPs containing dynamic stretching exercises that aim to improve flexibility and range of motion may also contribute to IRR reduction. For instance, all FIFA-based studies (along with 2 alternate others[9,11]) that had significant IRR reductions and provided relative weight in the meta-analysis contained dynamic stretching exercises (eg, “walking lunges,” “plant and cut,” “running with hips in and out”) along with strength and balance components. These dynamic exercises stretch key extensors and flexors of the lower limbs and, if done in the midst of higher-intensity training, can help to improve flexibility[29] and protect against muscle strain injuries, thereby reducing IRRs.

Implications

IPP efficacy holds significant clinical and applied implications for orthopaedics and physical therapists, as well as strength and conditioners, coaches, and sport organizations, respectively. IPPs reduce sporting injury rates (eg, overuse injuries) and thus reduce subsequent onward individual, social, and economic costs from injury immobility, treatment, and rehabilitation. As shown in individual studies (and now meta-analytically pooled), effective IPP content that is structured and multifaceted with frequent, stable, and consistent implementation over a long-term period will reduce injury risk. Findings also highlight how IPPs need to be practically tailored with respect to sport-specific training and competition and in terms of home-based exercises. Overall, clinical and sports practitioners can respectively recommend and implement IPPs similar to those examined as part of an injury prevention strategy.

Study Limitations and Recommendations

In the present study, some factors could not be examined owing to a lack of available or reported data; as such, factors were not of primary interest in the studies identified. These included chronological and biological age, skill level, compliance rates, and the dose-response effects of IPPs. Chronological and biological age (ie, maturational status, peak growth)[1,38] as well as skill level[36] in adolescence are known risk factors associated with particular types of injuries. Therefore, future high-quality studies will need to carefully account for such factors. This will also help determine whether IPPs can generally reduce injury risk (or just particular types) across and within stages of chronological, biological, and skill development.

CONCLUSION

When synthesized across 10 studies (9 RCTs), IPPs versus control or normative practice significantly reduced the IRR in adolescent team sport athletes by an estimated 40% (pooled IRR = 0.60, 95% CI = 0.48-0.75, bias adjustment = 32%). Structured IPPs reduce injury rates and thereby help to reduce the subsequent individual, economic, and social costs associated with immobility, treatment, and rehabilitation. The underlying explanations for IPP benefits remain to be accurately identified, but viable explanations relate to muscular strength, proprioceptive balance, and flexibility improvement, which overall improve physical preparedness for sport participation. Further RCTs that adhere to standardized approaches for injury reporting, exposure monitoring, as well as reporting greater information on participants (eg, age, maturation status, skill level) and intervention compliance will help to identify moderating factors and the protective mechanisms of IPPs.

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