Effectiveness of Multi-Component Interventions on Injury Risk Among Ice and Snow Sports Participants - A Systematic Review and Meta-Analysis

Zhanjiang Fan (fanzhanjiang45@gmail.com)
Xinjiang Normal University
Lanbin Min
Xinjiang Normal University
Wenbin He
Xinjiang Normal University
Yaorong Yang
Xinjiang Agricultural University
Wen Ma
Xinjiang Normal University
Jiayi Yao
Middle School of Urumqi

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Abstract

Background: Ice and snow sports, inherently high-risk due to their physically demanding nature, pose significant challenges in terms of participant safety. These activities increase the likelihood of injuries, largely due to reduced bodily agility and responsiveness in cold, often unpredictable winter environments. The critical need for effective injury prevention in these sports is emphasized by the considerable impact injuries have on the health of participants, alongside the economic and social costs associated with medical and rehabilitative care. Consequently, the development and implementation of cost-effective injury prevention strategies are vital. Such strategies, when well-executed, can substantially reduce both the frequency and severity of injuries, thereby significantly enhancing the safety and long-term viability of these challenging sports.

Objective: The study's objective is to rigorously assess and statistically substantiate the efficacy of diverse injury prevention strategies in ice and snow sports, aiming to bolster future safety measures with solid empirical evidence.

Design: Systematic review and meta-analysis.

Methods: The overarching aim of this research was to meticulously aggregate and scrutinize a broad spectrum of scholarly literature, focusing on the quantifiable efficacy of diverse, multi-component intervention strategies in mitigating injury incidences within the realm of ice and snow sports. This endeavor entailed an exhaustive extraction of data from esteemed academic databases, encompassing publications up to September 30, 2023. In pursuit of methodological excellence and analytical rigor, the study employed advanced bias assessment methodologies, notably AMSTAR 2 and the GRADE approach, alongside sophisticated random-effects statistical modeling. This comprehensive approach was designed to ensure the utmost validity, reliability, and scholarly integrity of the study's findings.

Results: The study analyzed 15 papers including 9 randomized controlled trials, 3 case-control, and 3 cohort studies with 26,123 participants and 4,382 injuries. Findings showed a significant reduction in injury rates through various interventions: overall injury prevention (RR = 0.50, 95% CI 0.42-0.63), educational training (RR = 0.50, 95% CI 0.34-0.73), educational videos (RR = 0.53, 95% CI 0.34-0.81), protective equipment (RR = 0.64, 95% CI 0.46-0.87), and policy changes (RR = 0.28, 95% CI 0.16-0.49). Subgroup analysis revealed potential heterogeneity in compliance ($p = 0.347$). Compared to controls, multi-component interventions effectively reduced injury rates.

Conclusion: This study's findings substantiate the pronounced efficacy of multi-component interventions in diminishing injury occurrences in ice and snow sports, underscoring the imperative for future scholarly endeavors to engage in diverse, high-caliber experimental research. This approach is crucial to generate more reliable evidence, thereby informing and refining practical, evidence-based injury prevention strategies.

1 INTRODUCTION

In the scholarly realm of sports science, the term "ice and snow sports" comprehensively encapsulates a variety of activities conducted on icy and snowy terrains, such as skating, skiing, and other recreational pursuits in these environments. Empirical evidence underscores the significant role of these sports in augmenting adolescent physical health, including their instrumental contribution to mitigating psychological disorders, curbing obesity, forestalling diseases, and fortifying physical fitness[1, 2, 3]. In recent times, these activities have witnessed a remarkable evolution, transitioning from seasonal to year-round engagements and attracting a diverse and expanding participant demographic. Notably, sports like snowboarding and skiing have emerged as trendy activities among adolescents, marking a cultural shift in the perception and adoption of these sports [4, 5].

Nevertheless, these sports are not without their risks. Participants engaging in dynamic movements such as acceleration, deceleration, turning, jumping, gliding, rolling, and landing are subject to a spectrum of potential injuries, ranging from minor to severe, encompassing head, upper limb, back, and lower limb traumas, and in extreme cases, fatalities [6, 7, 8, 9, 10, 11, 12]. This underscores the necessity for efficacious injury prevention strategies, aimed at diminishing both the likelihood and severity of such incidents. Furthermore, the management of sports injuries incurs substantial medical and societal costs, heightening the urgency for research dedicated to devising preventative measures. Such research endeavors are crucial, as they seek to balance the health-enhancing benefits of ice and snow sports with the imperative of ensuring participant safety [13].

From 1990 to 2000, research primarily focused on the effectiveness of protective gear, such as helmets [9, 14, 15, 16], wrist guards, and external joint supports [6, 7, 17, 18]. Between 2000 and 2010, the number of randomized controlled trials studying injury prevention in ice and snow sports nearly doubled [19], evaluating the effectiveness of protective measures. The past decade has seen a continued increase in comprehensive analyses of ice and snow sports injuries. Recent studies have shifted focus towards educational training programs [11, 20], educational videos [14, 21], and changes in ice and snow sports policies and regulations [8, 10, 11, 12, 22, 23], exploring the effectiveness of various intervention measures. Although previous reviews and experimental studies have evaluated the efficacy of certain specific programs [24], the diversity in content, design, target populations, and outcome reporting across different studies has limited the effective utilization of research findings. Meta-analysis can provide more comprehensive evidence in this context. Thus, our research aims to assess the effectiveness of multifaceted intervention programs in reducing injury rates and specific regional injuries, considering various age groups (children, adolescents, adults) and levels of sport participation (amateur, club, elite, mixed).

Therefore, this study adopts a meta-analysis approach, encompassing a wide range of studies from experimental to observational, to evaluate the effectiveness of various prevention and intervention strategies in ice and snow sports. It reviews relevant case-control studies, cohort studies, experimental, and quasi-experimental research literature from the past 30 years to gain a comprehensive understanding of the injury patterns and effective prevention methods in different activities. The researchers aim to capture studies employing rigorous methodologies, such as randomized controlled trials, to ensure that intervention measures are evaluated under strict scientific standards. The study uses six moderating variables for subgroup stratified analysis: age groups, types of injuries, skill levels, duration of intervention, and types of activities, to explore the specific impact of multifaceted intervention measures on injuries in ice and snow sports. It assesses the effectiveness of various prevention and intervention strategies in ice and snow sports, providing evidence-based recommendations for injury prevention in this field, benefiting practitioners and policymakers in the sector.

2 Methods

2.1 Search strategy

Within the academic sphere of sports science, with a particular emphasis on the prevention of injuries in ice and snow sports, a comprehensive and systematic literature search was meticulously executed to collate and analyze evidence-based strategies and types of interventions. Adhering scrupulously to the methodological protocols delineated in the Cochrane Handbook [25]. a duo of researchers embarked on an exhaustive and independent exploration of several prominent databases, including Google Scholar, PubMed, EMBASE, Web of Science, and SPORTDiscus. This search was characterized by an absence of constraints regarding publication dates, extending up to December 31, 2022. The investigative process encompassed an array of search terms intricately associated with interventions, prevention, and prophylactic measures within the realm of ice sports (such as speed skating, figure skating, ice hockey, and curling) and snow sports (encompassing skiing, snowboarding, cross-country skiing, and alpine skiing). Additionally, the search criteria incorporated terms related to injuries, sports injuries, case studies, randomized controlled trials, and the assessment of intervention effectiveness. Employing various permutations and combinations of these keywords, the researchers ensured a thorough and expansive coverage of the relevant literature. The search process was continuously updated and refined until September 30, 2023, thereby guaranteeing the inclusion of the most current and pertinent studies in this evolving field of research.

2.2 Document recognition

A researcher conducted a search in electronic databases, identifying a total of 9,756 studies, which were subsequently saved in Zotero. After removing duplicate studies, 7,926 studies remained. An initial screening of titles and abstracts led to the exclusion of 7,767 articles, leaving 159 studies. Following a full-text review of these studies, a further 145 were excluded. Additionally, a manual search of related literature and citation tracking included one more study. Of these, 103 studies were excluded for not reporting specific injury data, and 42 studies did not meet the criteria for randomized controlled trials, case-control studies, or prospective cohort studies. Ultimately, 15 studies were included in the meta-analysis (Fig. 1).

2.2.1 Inclusion Criteria

In the meticulous process of study selection, two academically qualified researchers will independently scrutinize the titles and abstracts of pertinent studies. Each study will undergo a comprehensive full-text assessment by these researchers if it aligns with the following rigorously defined inclusion criteria: (1) The study's central theme must be explicitly aligned with the prevention of injuries in the domain of ice and snow sports; (2) The methodological design of the study should be structured as either a cohort study, case-control study, or a randomized or cluster-randomized trial, ensuring a robust and scientifically sound approach; (3) The publication must delineate at least one objective and quantifiable outcome, encompassing metrics such as injury rates, the total number of injuries, or the duration of the intervention, to provide measurable insights into the effectiveness of the interventions; (4) The results presented in the study must convincingly demonstrate the efficacy of the interventions in mitigating injury risks in ice and snow sports. In instances of discordance or disagreement regarding the eligibility of a specific article, the two researchers will engage in a consensus-building dialogue to resolve any discrepancies. Should a consensus remain elusive, a third researcher, equipped with the requisite expertise, will be enlisted to provide an adjudicative decision, thereby ensuring the integrity and scholarly rigor of the study selection process.

2.2.2 Exclusion Criteria

The criteria for excluding literature include the following points: (1) Studies that do not provide a Risk Ratio (RR) or injury rates (RR), or where the original data cannot be used to calculate the required data (for example, cohort studies that use absolute rather than relative injury rates); (2) Studies that report only mortality rates without injury rates; (3) Studies that only compare the risks of injuries in ice and snow sports or the factors influencing these injuries; (4) Studies that report only other data related to ice and snow sports. In summary, articles that do not provide data allowing for the calculation of risk statistics, or that do not provide sufficient data to calculate the injury rate ratios (RR), will be excluded.

2.3 Data extraction

Data relevant to each study were extracted from the full texts that were included. Our objective was to assess the effectiveness of multifaceted intervention measures in preventing injuries among participants in ice and snow sports. The types of multifaceted interventions primarily included: (1) Educational training programs, designed to enhance awareness and knowledge regarding injury prevention; (2) Educational videos, which visually communicate safety protocols and preventive strategies; (3) Modifications in policies and rules, aimed at instituting safer practices and environments; (4) Use of protective equipment, serving as a physical barrier against injury. The injury rates for four types of injuries were analyzed separately: (1) Head injuries; (2) Upper limb injuries; (3) Lower limb injuries; (4) All injuries. Table 1 provides a detailed description of the multifaceted interventions and injury categories.

Table 1
Types of multi-component intervention and injury.

Study outcome	Description	
educational training	ISPAInt	(1) eccentric hamstring strength : Dynamic Bridging,Nordic Hamstring Exercise.
		(2) leg axis stability by strengthening the external hip rotators : Deep Single Leg Pistol Squats.
		(3) trunk stability by improving the strength and neuromuscular coordination of the trunk muscles : Dynamic Planking, Deadbug Bridging.
	NMT program	including aerobic; strength; balance; and agility components et al.
Educational video		(1) educational video of ice and snow sports safety knowledge, behavior and attitude.
		(2)ice and snow sports safety brochure
		(3) ice and snow sports equipment wearing video and theoretical guidance.
Policy changes		(1) Infrastructure construction.
		(2) personnel training and public participation.
		(3)rules of ice and snow sports, including competition rules, protective measures and technical standards
Protective equipment		Helmet; wrist guard; facial protector and tooth guard.
Head injurys		(1) scalp injury.
		(2) skull fracture.
		(3) brain injury.
Upper limb injurys		(1) finger and palm injury.
		(2) injury of elbow joint and forearm.
		(3) shoulder and upper arm injury.
Lower extremity injuries		(1)damage to the bones, nerves, blood vessels and muscles of the lower extremities
		(2)knee joint injuries, acute knee injuries, undefined knee injuries, ankle injury
		(3)ACL injuries, non-contact ACL injuries
All injiuries		(1)all sports injuries, all injuries
		(2)Injuries and abrasions on all parts of the body

We extracted the characteristics of the participants, the type of sport, the level of sport, the duration of the intervention, and the main outcomes from each article (Table 2). The calculations for the meta-analysis were conducted using the Collaboration Review Manager 5.1 software. All calculations were based on the primary outcomes of the studies. Our research analyzed the data by calculating Risk Ratios (RR), injury rate RRs, or using Cox regression RRs [33]. The calculation of the injury rate ratio (RR) is as follows: RR = (number of injuries in the intervention group/duration of intervention) / (number of injuries in the control group/duration of intervention). An injury rate odds ratio RR > 1 indicates that the intervention effect is not significant or ineffective, while an RR < 1 suggests the effectiveness of multifaceted intervention measures in reducing injuries [26], meaning that an RR of 0.42 corresponds to a 58% reduction in injuries. The injury rate ratio (RR) with a 95% confidence interval was used as the measure of effect size for analysis. The inverse variance was used as the statistical method, and the analysis was based on a random-effects analysis model. Statistical heterogeneity was assessed using I^2 and χ2 (Q) values; heterogeneity is considered low for I^2 values between 25–50%, moderate for 50–75%, and high for ≥ 75% [25]. Tri-tailed or bi-tailed P-values < 0.05 were considered statistically significant.

Table 2
Characteristics of included trials and quality evaluation.

Study	Intervention	Age	Session	Level	Sport	Outcome (injuries)	Compli-anc %	Quality grade
Schoeb et al., 2022	ISPAInt	13–15	48 week	Elite	Alpine skiing	All	100	High(10)
Priyambada et al., 2023	Educational video	7–16	2 week	Primary	Skiing	All	87	High(9)
Hagel et al., 2005	Protective equipment	< 15; 15–25; ≥26	24 week	Club	Skiing / snowboarding	Head	77	Mediu(8)
Hasler et al., 2010	Protective equipment	19–20	24 week	Club	Skiing / snowboarding	Head	78	Mediu(7)
Emery et al., 2004	NMT plan	11–15	12 week	Club	Ice hockey	All / limb	97	High(11)
Ytterstad et al., 1996	Education/ Protective equipment	0–14; ≥15	3 year	Club	Skiing/Ice hockey	Head/ All	87	Mediu(8)
Cusimano et al., 2013	Educational video	11–12	16 week	Primary	Skiing / snowboarding	Upper limb	93	Low(7)
Machold et al., 2002	Protective equipment	11–17	1 week	Primary	Skiing / snowboarding	Upper limb	65	Low(7)
Jørgensen et al., 1998	Educational video	5–61	8 week	Mix	Alpine skiing	All	83.2	Mediu(8)
Westin et al., 2020	Core stability/ NAM plan	14–18	2 year	Primary	Alpine skiing	Lower limb	100	High(11)
Rønning et al., 2001	Protective equipment	10–68	12 week	Mix	Skiing / snowboarding	Upper limb	67	Low(7)
Kolstad et al., 2023	policy changes /Protective equipment	11–18	5 year	Club	Ice hockey	Head	87.3	High(8)
Black et al., 2017	policy changes	11–12	2 4week	Club	Ice hockey	Head/All	92	High(8)
Emery et al., 2010	policy changes	11–12	24 week	Club	Ice hockey	Head	84	Mediu(7)
Benson et al., 2002	Protective equipment	All	24 week	Club	Ice hockey	Head injuries	78	Mediu(6)

2.4 Quality Evaluation

In accordance with the recommendations of AMSTAR 2 [27], the credibility of each included experiment was assessed to categorize the research studies. Two researchers evaluated each study based on the fulfillment of evaluation criteria, marking them as "yes," "no," or "partly yes" for some entries. Depending on the potential impact on the study results, each credibility level was judged as high, moderate, low, or very low. A study was rated as "high" if there were 0 or 1 non-critical items with flaws; "moderate" if there were more than 1 non-critical items with flaws. If there was 1 critical item with or without non-critical items with flaws, the study was rated as "low." If there were more than 1 critical items with or without non-critical items with flaws, it was rated as "very low." The two researchers independently reviewed the credibility and resolved any discrepancies through consensus among all researchers.The quality of evidence and the strength of recommendations were evaluated using the GRADE system [28].. Researchers considered four key elements of the articles: study design, study quality, consistency, and directness. Criteria for assigning evidence levels were: (1) randomized controlled trials were rated as high-level; (2) observational studies as moderate-level; (3) other studies as low-level. The level was downgraded under the following conditions: (1) Poor study quality lowered by 1 level, very poor by 2 levels; (2) Poor consistency lowered by 1 level; (3) Large uncertainty in directness lowered by 1 level, very large by 2 levels; (4) Unclear data reporting lowered by 1 level; (5) High risk of bias lowered by 1 level. The level was upgraded under the following conditions: (1) Consistency of two or more pieces of evidence, significant and low risk of bias, increased by 1–2 levels; (2) Strong direct evidence, significant and low risk, increased by 2–5 levels, the validity of the evidence increased by 2 levels; (3) Increasing degrees of evidence raised by 1 level; (4) All potential factors reduced increased by 1 level. Publication bias was assessed through visual inspection of funnel plots and the bi-tailed Egger test [29]. Finally, the evidence was categorized into four levels: high, moderate, low, and very low. Based on this, a systematic analysis of the literature was conducted, including 9 randomized controlled trials, 3 case-control and case-crossover studies, and 3 prospective cohort studies, totaling 15 studies with 27 valid data points. Using 12 quality criteria adapted from Furlan [50], two researchers independently scored the methodological quality (Table 2), with the highest score being 11/12, the lowest score 7/12, and the average score 8/12.

2.5 Publication Bias

Based on the studies identified, the funnel plot (Fig. 2) showed that the effect sizes were relatively evenly clustered in the upper effective area, suggesting a symmetric distribution. To avoid a single study generating too many effect values and occupying excessive weight, potentially causing bias in the results, this study adopted a method of effect value aggregation for articles containing various conditions. If an experiment reported the effects of multiple interventions and these interventions were not the moderating variables of interest in this study, they were converted into a single effect size. Furthermore, to ensure the independence of effect values, if an experiment reported multiple test results from the same sample, CMA 3.0 was used to combine these effect values before including them in the meta-analysis.Egger's test was used to confirm asymmetry. The larger the deviation of the intercept from zero, the more apparent the asymmetry. If the p-value of the intercept is equal to or less than 0.1, the asymmetry is considered statistically significant (Intercept = -2.08, SE = 0.69, P = 0.003) [30].. The Fail-Safe Number (Nfs) test criterion is Nfs value greater than 5N + 10, where N represents the number of studies. This criterion, as proposed by Rosenthal [31, 32], estimates how many unpublished and non-significant study samples would be needed to render the current meta-analysis results insignificant. The result showed Nfs = 926, which is greater than 5x27 + 10 = 145, indicating that the likelihood of a change in the results of this meta-analysis is minimal. Based on these findings, we concluded that there was no publication bias in the included studies, and the results of the meta-analysis are valid and reliable.

3 RESULTS

Through literature search, review, and selection, among the 15 studies included in our analysis, we focused only on initial injuries, as repeated results are likely interdependent, potentially leading to bias. The included studies comprise 5 European Randomized Controlled Trials (RCTs)[6, 7, 11, 14, 20], 3 Canadian RCTs [8, 18, 21], 1 prospective RCT from the United States [17], and 3 prospective cohort and case-control studies from Canada and Switzerland [9, 10, 12]. Additionally, there were 3 prospective cohort studies from Canada [15, 16, 22]. The studies involved a total of 26,123 participants, including both males and females, with an age range covering children (0–12 years), adolescents (13–19 years), and adults (20 years and older). The number of participants in these studies varied from 69 to 6,266 [12, 18]. A total of 4,382 injuries were reported across the studies, with intervention durations ranging from 1 week to 144 weeks [7, 17]. All interventions were applied at least twice weekly in the intervention groups, while control groups underwent regular training.Subgroup analyses were further conducted, including variables such as age, duration of intervention, level of sport, and type of ice and snow sport. Age was categorized into children, adolescents, and adults; sport level into elite, club, and amateur; intervention duration into less than or equal to 2 weeks, 8–12 weeks, and more than 12 weeks; and ice and snow sports included skiing, snowboarding, alpine skiing, and ice hockey.

3.1 Overall exercise intervention effect

In the 15 studies included, the overall impact of different interventions on the prevention of injuries in ice and snow sports showed a total injury rate ratio (RR) of 0.50 (95% CI 0.41–0.62; I^2 = 76.56%; T^2 = 0.195; p < 0.001) (Fig. 3). This indicates that compared to the control group, the injury rate ratio in the intervention group was reduced by 50% (1-0.50), meaning the injury rate in the intervention group was 50% lower than that in the control group. The 95% CI of 0.41–0.62 suggests that at a 95% confidence level, there is a 95% probability that the true injury rate ratio lies between 0.41 and 0.62, indicating some degree of uncertainty about this injury rate ratio. It is important to note that this confidence interval does not include 1, and a p-value of < 0.001 signifies that the injury prevention effect is significant, meaning the injury rate ratio in the intervention group is significantly lower than in the control group (Fig. 3). The Q value of 110.91 (df = 26, P < 0.001) highlights variability in the true effect sizes across all studies. An I^2 of 76.56% indicates that approximately 77% of the variance observed in the effects is due to true effects. The T^2 and T values are 0.195 and 0.442, respectively, further emphasizing the heterogeneity observed in the study results.

3.1.1 educational training

The effectiveness of educational training interventions in reducing injuries in ice and snow sports was studied in 3 experiments involving a total of 1,590 participants [8, 11, 20]. The educational training programs included the ISPAInt program and high-intensity neuromuscular training (NMT) program. The injury rate ratio (RR) for ice and snow sports participants subjected to educational training interventions was RR = 0.50 (95% CI 0.34–0.73; I^2 = 84.61%; T^2 = 0.223; p < 0.001) (Fig. 4). This indicates that educational training interventions can significantly reduce the overall injury rate. Specifically, an RR of 0.50 implies that the injury rate in groups receiving educational training interventions was 50% lower than in those without such interventions. The 95% confidence interval (CI) of 0.34–0.73 suggests that there is a 95% probability that the true RR lies within this range in similar studies. An I^2 of 84.61% indicates substantial heterogeneity in the results, warranting cautious interpretation. The T^2 value of 0.223 suggests a small variance between different studies, which could be due to differences in study designs, sample sizes, and intervention measures. The p-value of < 0.001 indicates that the difference in results is statistically significant. Overall, these results suggest that educational training interventions can reduce the overall injury rate in ice and snow sports. However, the high heterogeneity and variance should be taken into consideration.

3.1.2 Educational Video

In the three included studies on educational video interventions, comprising a total of 3,180 participants[14, 18, 21], the impact of educational video interventions on the risk of injuries among ice and snow sports participants was investigated. The injury rate ratio (RR) for participants exposed to educational video interventions compared to the control group was RR = 0.53 (95% CI 0.34–0.81; I^2 = 62.72%; T^2 = 0.238; $p < 0.001$) (Fig. 4). This suggests that educational video interventions can significantly reduce the overall injury rate. Specifically, an RR of 0.53 indicates that the injury rate in groups receiving educational video interventions was 47% lower than in those without such interventions. The 95% confidence interval (CI) of 0.34–0.81 implies that in similar studies, there is a 95% probability that the true RR lies within this range.

An I^2 of 62.72% indicates moderate heterogeneity in the results, while a T^2 of 0.238 suggests a small variance between different studies. The p-value of < 0.001 indicates that the difference in results is statistically significant. Overall, these results demonstrate that educational video interventions can effectively reduce the overall injury rate in ice and snow sports.

3.1.3 Policy changes

Two prospective cohort studies involving a total of 1,848 participants examined the impact of policy and rule changes on the injury risk among ice hockey players[8, 10]. Compared to the control group, the injury rate ratio (RR) for ice hockey players subjected to interventions involving changes in policy and rules was found to be RR = 0.28 (95% CI 0.16–0.49; I^2 = 63.24%; T^2 = 0.152; $p < 0.001$) (Fig. 4). This indicates that interventions involving policy and rule changes can significantly reduce the overall injury rate. Specifically, an RR of 0.28 suggests that the injury rate after such interventions was 72% lower than in groups without these interventions. The 95% confidence interval (CI) of 0.16–0.49 implies that in similar studies, there is a 95% probability that the true RR lies within this range.

An I^2 of 63.24% indicates moderate heterogeneity in the results, while the T^2 of 0.152 suggests a small variance between different studies. The p-value of < 0.001 indicates that the difference in results is statistically significant. Overall, these results demonstrate that interventions involving policy and rule changes can effectively reduce the overall injury rate in ice hockey sports.

3.1.4 Protective Equipment

In a total of 7 experiments involving 19,545 participants, the effectiveness of protective equipment in reducing injury risk among ice and snow sports participants was studied. The protective equipment mainly included helmets [9, 12, 16], wrist guards [6, 7], and facial protection including mouthguards [15]. These participants included alpine skiers, skiers, snowboarders, and ice hockey players.In 5 experiments evaluating head and facial injuries [9, 12, 17, 15, 16], involving 13,755 participants, helmets, and facial protection including mouthguards were found to effectively protect ice and snow athletes from head injuries. In 2 experiments assessing upper limb injuries (wrist and shoulder) involving a total of 5,790 participants, wrist guards or external joint supports effectively protected against wrist injuries [6, 7] .

Based on the effectiveness studies of protective equipment across 7 experiments, the interventions collectively reduced injuries in various body parts compared to the control groups, with an injury rate ratio of RR = 0.64 (95% CI 0.46–0.87; I^2 = 58.13%; T^2 = 0.087; $p < 0.01$) (Fig. 4). This indicates that protective equipment interventions can significantly reduce the overall injury rate. Specifically, an RR of 0.64 suggests that the injury rate after protective equipment interventions was 36% lower than in groups without these interventions. The 95% confidence interval (CI) of 0.46–0.87 implies that there is a 95% probability that the true RR lies within this range in similar studies. An

I^2 of 58.13% indicates moderate heterogeneity in the results, while a T^2 of 0.067 suggests a small variance between different studies. The p-value of < 0.004 indicates that the difference in results is statistically significant. Overall, these results demonstrate that interventions involving protective equipment can effectively reduce the overall injury rate in ice and snow sports.

3.2 Subgroup Analysis

The subgroup analysis primarily focused on the injury rates among ice and snow sports participants and the results of mixed-effects application of a random model across five moderating variables (Table 3). A comparison between subgroups revealed only one significant difference ($p = 0.347$). This finding offers insights for interpreting the qualitative sources within our study. On one hand, it can help explain the variance among studies. On the other hand, it suggests that elite athletes, through years of training and competition experience, have developed good sports habits. Consequently, intervention measures may not be as significantly impactful for elite athletes as they are for other groups. This lack of significant impact on elite athletes can be attributed to their already established and effective injury prevention practices and heightened awareness and skill level in their respective sports.

Table 3
Subgroup Analyses According to Identified Moderating Factors

Moderator	Mixed-Effects Analysis Between-Subgroup Comparison							Subgroup Heterogeneity			
	K_R	ES	95%CI	P_b-value	P-RR-R (%)	Q_b-value (df)	P_b-value	Q_w[c]-value(df)	P_w[d]-value	I^2	T^2
Types of injuries						1.65 (3)	0.65				
Head	6	0.51	0.29–0.89	.019	49			33.41 (5)	< .001	85.04	0.39
Upper limb	4	0.42	0.19–0.94	.035	58			8.84 (3)	.032	66.06	0.37
Lower limb	5	0.41	0.28–0.60	< .001	59			8.63 (4)	.071	53.65	0.09
All	12	0.56	0.41–0.77	< .001	44			46.52 (11)	< .001	76.36	0.21
Age group						26.26 (3)	0.00				
Children	7	0.30	0.23–0.38	< .001	70			6.04 (6)	< .001	0.74	0.00
Teenagers	10	0.62	0.43–0.89	.009	38			22.30 (4)	< .001	82.06	0.13
Adult	10	0.68	0.57–0.80	.000	32			35.59 (9)	< .001	74.71	0.25
Exercise level						3.12 (3)	0.37				
Elite	2	0.78	0.47–1.30	.347	-			6.49 (1)	.011	84.60	0.11
Club	11	0.46	0.33–0.66	< .001	54			55.95 (10)	< .001	82.13	0.26
Primary	8	0.51	0.35–0.75	.001	49			15.34 (7)	.032	54.38	0.13
Mix	6	0.45	0.25–0.81	.007	55			20.74 (5)	.001	75.89	0.40
Duration						4.08 (2)	0.13				
≤ 2w	5	0.70	0.54–0.91	.007	30			4.26 (4)	.372	6.09	0.01
8-12w	5	0.49	0.26–0.95	.035	51			18.03 (16)	.001	77.81	0.43

Moderator	Mixed-Effects Analysis Between-Subgroup Comparison							Subgroup Heterogeneity			
	K_R	ES	95%CI	P_b-value	P-RR-R (%)	Q_b-value (df)	P_b-value	$Q_w{}^c$-value(df)	$P_w{}^d$-value	I^2	T^2
≥ 12w	17	0.48	0.37–0.63	< .001	52			86.13 (1)	< .001	81.42	0.23
Ice and snow types											
Alpine skiing	9	0.64	0.47–0.86	.003	36	3.96 (2)	0.14	30.95 (8)	< .001	74.15	0.14
Skiing / snowboarding	10	0.51	0.34–0.76	.001	49			26.48(9)	.002	66.01	0.22
Ice hockey	8	0.38	0.25–0.57	< .001	62			35.10 (7)	< .001	80.06	0.26

Note: Q value, total or subgroup effect value study dispersion.K, No. of Studies, R, Random-effects model; ES, Effect size damage rate ratio; P-RR-R.Possible RR, Reduction; b, Total between. w, Total within; 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;heterogeneity in I^2, T^2, subgroup.

3.2.1 Types of injuries

The subgroup analysis for types of injuries revealed the following: For head injuries, the injury rate ratio (RR) was RR = 0.51 (95% CI 0.29–0.89; I^2 = 85.04%; T^2 = 0.386; $p < 0.01$). This indicates a statistically significant reduction in the rate of head injuries as a result of the interventions. For upper limb injuries, the RR was RR = 0.42 (95% CI 0.19–0.94; I^2 = 66.06%; T^2 = 0.374; $p < 0.05$). This suggests a significant reduction in the rate of upper limb injuries. For lower limb injuries, the RR was RR = 0.41 (95% CI 0.28–0.60; I^2 = 53.65%; T^2 = 0.094; $p < 0.001$), indicating a significant reduction in lower limb injuries. For injuries to the entire body, the RR was RR = 0.56 (95% CI 0.41–0.77; I^2 = 76.36%; T^2 = 0.208; $p < 0.001$), which is also statistically significant.

The study found that multifaceted intervention measures were more effective for lower and upper limb injuries compared to head and overall body injuries (RR = 0.42 vs 0.51 and 0.56). This differential effectiveness could be related to the specific characteristics of ice and snow sports activities. For example, the nature of these sports might pose greater risks for limb injuries, making interventions targeting these areas particularly effective. The high degree of heterogeneity (I^2 values) also suggests variability in the effect sizes across the studies, which might be attributed to differences in the types of sports, intervention methods, and participant characteristics.

3.2.2 Age group

Subgroup Analysis by Age Group: For children (< 12 years), the injury rate ratio (RR) was RR = 0.30 (95% CI 0.23–0.38; I^2 = 0.74%; T^2 = 0.001; $p < 0.001$). This indicates a significant reduction in injury rates in children as a result of the interventions. For adolescents (12–19 years), the RR was RR = 0.62 (95% CI 0.43–0.89; I^2 = 82.06%; T^2 = 0.134; $p < 0.01$). This suggests a substantial but less pronounced reduction in injury rates compared to children. For adults

(≥ 20 years), the RR was RR = 0.68 (95% CI 0.57–0.80; $I^2 = 74.71\%$; $T^2 = 0.253$; $p < 0.01$), indicating a significant reduction in injury rates, although the effect is less compared to children.

The analysis found that multifaceted intervention measures were more effective in children and adults compared to adolescents. This outcome aligns with cognitive development patterns: children, having lower self-protection awareness, are more susceptible to intervention measures and possess stronger learning capabilities and a greater willingness to accept new practices. Adults, with their rich knowledge and strong self-protection awareness, are also more receptive to interventions. Adolescents, often seeking thrill and adventure, are more likely to indulge in risky behavior, making them more prone to accidents and injuries during sports activities. The significant heterogeneity (I^2 values) among adolescents and adults suggests variability in the effect sizes across different studies, possibly due to variations in intervention methods, sports types, and individual characteristics of the participants within these age groups.

3.2.3 Exercise Level

The subgroup analysis by exercise level revealed the following: For elite-level athletes, the injury rate ratio (RR) was RR = 0.78 (95% CI 0.47–1.30; $I^2 = 84.6\%$; $T^2 = 0.114$; $p = 0.347$), which is not statistically significant. This suggests that interventions had a less pronounced impact on reducing injuries among elite athletes. For club-level athletes, the RR was RR = 0.46 (95% CI 0.33–0.66; $I^2 = 82.13\%$; $T^2 = 0.264$; $p < 0.001$), indicating a significant reduction in injury rates at this level. For amateur-level athletes, the RR was RR = 0.51 (95% CI 0.35–0.75; $I^2 = 54.38\%$; $T^2 = 0.126$; $p < 0.001$), also showing a significant reduction in injury rates.For mixed levels, the overall injury rate was RR = 0.45 (95% CI 0.25–0.81; $I^2 = 75.89\%$; $T^2 = 0.401$; $p < 0.01$), which is statistically significant.

The analysis indicates that multifaceted intervention measures were most effective for club-level participants, followed by amateur-level athletes, with no significant impact observed for elite-level athletes. The high heterogeneity (I^2 values) across different levels, especially among elite and club-level athletes, suggests variability in the effect sizes, possibly due to differences in the intensity and nature of the sports activities, the athletes' experience, and the specific types of interventions used. The lack of significant impact on elite athletes might be attributed to their already high level of training, awareness, and injury prevention practices. In contrast, club and amateur athletes might benefit more from interventions due to less exposure to professional training and injury prevention strategies.

3.2.4 Duration of Intervention

The subgroup analysis based on the duration of the intervention revealed the following: For interventions lasting ≤ 2 weeks, the injury rate ratio (RR) was RR = 0.70 (95% CI 0.54–0.91; $I^2 = 6.09\%$; $T^2 = 0.009$; $p < 0.01$). This indicates a significant reduction in injury rates for short-term interventions, with minimal heterogeneity among studies. For interventions lasting 8–12 weeks, the RR was RR = 0.49 (95% CI 0.26–0.95; $I^2 = 77.81\%$; $T^2 = 0.428$; $p < 0.05$). This suggests a more pronounced reduction in injury rates for medium-term interventions, although with a higher level of heterogeneity. For interventions lasting ≥ 12 weeks, the RR was RR = 0.48 (95% CI 0.37–0.63; $I^2 = 81.42\%$; $T^2 = 0.227$; $p < 0.001$). This indicates a significant reduction in injury rates for long-term interventions, again with considerable heterogeneity.

The subgroup analysis for the duration of the intervention shows that medium (8–12 weeks) and long-term (≥ 12 weeks) interventions were most effective, followed by short-term (≤ 2 weeks) interventions. The varying effectiveness based on duration suggests that while shorter interventions have an impact, more extended periods of intervention may be more effective in reducing injuries. The high I^2 values for the 8–12 weeks and ≥ 12 weeks durations indicate substantial heterogeneity, which could be due to variations in the types of interventions implemented, the sports involved, and the specific characteristics of the participants. Despite the heterogeneity, the consistent trend across all durations underscores the overall effectiveness of intervention measures in reducing injury rates in ice and snow sports.

3.2.5 Ice and Snow sports

The subgroup analysis based on the type of ice and snow sports revealed the following: For alpine skiing, the injury rate ratio (RR) was RR = 0.64 (95% CI 0.47–0.86; I^2 = 74.15%; T^2 = 0.136; $p < 0.01$). This indicates a significant reduction in injury rates in alpine skiing, though with considerable heterogeneity among studies. For skiing/snowboarding, the RR was RR = 0.51 (95% CI 0.34–0.76; I^2 = 66.01%; T^2 = 0.223; $p < 0.01$). This suggests a significant reduction in injury rates in skiing and snowboarding, with moderate heterogeneity. For ice hockey, the RR was RR = 0.38 (95% CI 0.25–0.57; I^2 = 80.06%; T^2 = 0.258; $p < 0.001$), indicating a significant reduction in injury rates and the highest effectiveness among the sports analyzed, again with considerable heterogeneity.

Our analysis elucidated that the efficacy of the interventions varied significantly across different ice and snow sports, with a pronounced effectiveness observed in ice hockey as compared to alpine skiing, skiing, and snowboarding. This differential impact may be attributed to the inherently intense physical contact and competitive ethos of ice hockey, which render it particularly amenable to the influence of policy and rule changes. The observed high levels of heterogeneity, as reflected in the I^2 values across these sports, indicate a notable variation in the effect sizes. This variability is likely a consequence of several factors, including the distinct nature of each sport, the specific types of interventions implemented, and the unique characteristics of the participant cohorts within each sporting discipline. The analysis further revealed a significant reduction in injury rates across all examined types of ice and snow sports, emphatically affirming the overarching effectiveness of interventions when they are meticulously tailored to meet the specific needs and inherent risks associated with each sport. This finding underscores the critical importance of developing and implementing bespoke intervention strategies that are finely attuned to the particularities of each sport, thereby optimizing their potential to mitigate injury risks and enhance participant safety. The nuanced approach to intervention design and implementation, cognizant of the unique attributes and demands of each sport, is paramount in effectively reducing injury rates and promoting the health and safety of athletes engaged in these diverse and challenging sporting activities.

4 DISCUSSION

4.1 Findings

The systematic review and meta-analysis, which included 9 Randomized Controlled Trials (RCTs), 3 case-control studies, and 3 prospective cohort studies, evaluated the evidence of the effectiveness of intervention measures on overall and specific area injuries among participants in ice and snow sports. Excluding the impact of objective factors such as environmental and geographical elements, the interventions focused on controllable factors like educational training, educational videos, protective equipment, and policy/rules changes in sports. Based on the injury rate ratios (RR) and 95% confidence intervals, it was demonstrated that intervention measures effectively reduced the risk of injuries among ice and snow sports participants. The analysis of the impact of multifaceted injury prevention interventions compared to control groups on overall and regional injury risks included I^2, p-values, RR, T^2, and the significance of $P < 0.001$, along with the certainty of all primary and secondary outcomes. Despite the significant preventive results indicated by the analysis, potential risks of bias exist. Moreover, most of the results are based on high efficacy.

The significant outcomes suggest that multifaceted interventions are effective in reducing injury risks in ice and snow sports. However, the variability in effects (indicated by I^2 values) and the potential biases underline the need for cautious interpretation of these findings. The high efficacy reported in most studies emphasizes the importance of such interventions in sports injury prevention but also highlights the necessity for continuous evaluation and potential refinement of these intervention strategies.

4.2 Comparison with Existing Literature

The aim of this study was to assess the effectiveness of multifaceted interventions in the prevention of injuries in ice and snow sports. Analyzing the injury rate ratio from this study and comparing it with those reported in previous research, our study includes participants of all ages and various skill levels in ice and snow sports (elite, club, amateur, and mixed). The injury rate ratio in this study was RR = 0.50 (95% CI 0.41–0.62; I^2 = 76.6%; T^2 = 0.195; $p < 0.001$), indicating a roughly 50% reduction in injury risk, which is at the upper limit reported in previous systematic reviews. This finding represents a statistically significant and clinically meaningful reduction in the prevention of injuries, similar to the reductions in injury rates reported in previous systematic reviews and meta-analyses. For example, in an educational ACL injury prevention video study, Schoeb et al. found the intervention to be effective in preventing lower limb and knee joint injuries (RR = 0.665 (95% CI 0.485–0.884) $p < 0.001$, RR = 0.699 (95% CI 0.493–0.989) $p < 0.001$) [20]. Lauersen et al. indicated that physical exercise interventions can reduce the risk of acute injuries by 35.3% (RR = 0.65, 95%CI = 0.50–0.84, $p < 0.01$) [33], while Hübscher et al. found that multiple intervention exercises effectively reduced the risk of lower limb injuries (RR = 0.61, 95% CI = 0.49–0.77, $p < 0.01$) and that balance training alone significantly reduced the risk of ankle sprains (RR = 0.64, 95% CI = 0.46–0.90, $p < 0.01$) [34].

A systematic review of early research on the prevention of sports injuries concluded that educational training had a significant impact as a prevention strategy [35]. Home-based balance training can improve static and dynamic balance and enhance postural control during movement, potentially reducing the risk of injury and may also improve proprioception and neuromuscular control [8]. The 50% intervention effectiveness in our study further supports the benefits of educational training, particularly in reducing the risk of lower limb joint injuries. 80% of effective educational training interventions included stability, balance, or coordination components [23], and 3 experiments with educational training interventions significantly reduced the risk of sports injuries and improved physical capabilities. In previous studies, lower limb injuries, especially anterior cruciate ligament (ACL) injuries, were a prominent issue. In our study, educational training programs primarily based on proprioceptive training significantly prevented lower limb injuries, but further detailed research is needed to determine whether they can reduce knee injuries. Additionally, the intervention group showed a lower average 2-week injury rate in traumatic knee injuries, knee overuse injuries, and lower back overuse injuries compared to the control group [11, 20, 36]. Our findings corroborate Schoeb et al.'s finding that youth skiers performing the ISPAInt program weekly at 0.8 ± 0.6 times had a lower absolute incidence of traumatic and overuse injuries. Westin et al. reported a 45% reduction in ACL injury rates among U18 skiers [11]. Therefore, high-quality implementation should be based on a partnership between program developers (researchers) and participants. Two experiments studied the impact of high-intensity neuromuscular training (NMT) programs on lower limb injuries[8, 11]. Emery et al.'s study showed protective effects for all injuries (RR = 0.30, 95% CI, 0.19–0.49), lower limb injuries (RR = 0.31, 95% CI, 0.19–0.51), ankle sprains (RR = 0.27, 95% CI, 0.15–0.50), and knee twists (RR = 0.36, 95% CI, 0.13–0.98). Emery et al.'s randomized control trial showed that adolescents who underwent 12 weeks of high-intensity NMT significantly reduced sports and muscle injury risks compared to the control group, with an RR of 0.82 (95% CI 0.71–0.94; 95% CI 0.58–1.15), though the effectiveness was not significant [24]. Rahnema et al.'s quasi-experimental study found significant correlations between improvements in balance and agility following 8 weeks of regular training and thrice-weekly core stability training among professional speed skaters ($p < 0.05$), indicating a positive impact on dynamic balance and agility [37, 38]. This reflects the overall trend in current injury prevention research: while external risk factors cannot be changed, cognitive level, physical fitness, muscle strength, motor skills, and athletic capabilities can be altered through various combinations of educational training interventions. Likewise, neuromuscular training is included in educational training interventions. According to the review, neuromuscular training is believed to have beneficial effects on joint position sense, stability, and reflexes. Neuromuscular training is a cost-effective training method that can effectively reduce injury risk without equipment. ISPAInt interventions and NMT strength training can effectively reduce overall injuries in ice and snow athletes [8, 20]. Interventional experimental studies aimed at strengthening power and neuromuscular training have not been widely conducted in ice and snow sports. Instead, strength and neuromuscular training have been successfully applied as part of multifaceted interventions, and almost all of these interventions include elements of strength, neuromuscular, balance, and coordination training. This comprehensive educational training program intervention might be the sum of all effective methods. It's nearly impossible to determine which part of the training intervention is the actual effective component and which has no impact on injury risk [35]. A combination effect may occur, but effective prevention must be based on high compliance with injury prevention programs by participants and organizers [39].

Educational video interventions were rated as 65% effective [40, 51], which is very similar to the findings of our study. Although our results carry potential biases, our research was based on participants of all ages and varying skill levels and considered differences among subgroups. Our analysis suggests that this type of intervention has significant potential in preventing sports injuries, warranting further research into the effectiveness of educational video interventions. Additionally, designing broader educational video intervention programs will inevitably increase with higher application dosages, potentially leading to reduced compliance. Our study indicates that the efficacy research for multifaceted intervention measures must be based on high-quality randomized controlled trials, with further research in randomized trials remaining crucial. For instance, Jørgensen et al. found that showing a 45-minute educational video during long bus trips to ski resorts for beginners, including basic skills and safety requirements, equipment checks, and helmet use, effectively reduced injury risks, especially for collisions and falls [14]. Ytterstad et al. provided past injury information and technical and safety tips to ski club members through brochures and educational videos, significantly reducing skiing injuries [17]. Priyambada et al. found that the injury risk in the intervention group was similar to the control group, with injury rates of 22.95/100 (95% CI: 17.63–28.26) in the intervention video group and 23.31/100 (95% CI: 16.75–29.87) in the control group, using standardized assessment tools to evaluate injury rates. They suggested understanding risky behaviors to optimize the promotion of safe practices to prevent injuries and appropriately incorporate them into injury prevention strategies [21]. Educational videos effectively raised injury awareness and safety prevention knowledge among children and adolescent skiers, similar to Jørgensen et al.'s findings. An intervention with snowboarding safety videos and manuals increased safety injury knowledge by 13.6% among Canadian 7th-grade (11–12 years old) students, a critical first step as children and adolescents face risks of preventable injuries, and early learning of safety strategies could lead to lifelong safety compliance [49].

Protective equipment is widely used to prevent injuries among participants in ice and snow sports, but its effectiveness varies. Early review studies have shown that helmet use by skiers can effectively reduce the risk of head injuries and may also help reduce neck and other injuries [7, 9, 14, 17, 41, 42], but it could also potentially increase the risk of head or neck injuries [43]. In ice and snow sports, a mandatory policy of wrist guard wearing implemented among middle school students (12–16 years) showed a significant decrease in wrist injury rates [44]. However, using wrist guards may increase the risk of injuries to the elbow, upper arm, and shoulder while reducing the risk to the hand, wrist, and forearm [16], possibly due to the transmission of impact forces along the kinetic chain of the limb.

In our study, 5 out of 7 experiments supported the use of protective equipment (such as helmets, face shields, and mouthguards) in effectively preventing head injuries [9, 12, 16, 17, 46]. These participants included alpine skiers, skiers, snowboarders, and ice hockey players. For instance, three case-control studies reported a reduced risk of head injuries in participants wearing helmets (reductions of 29%, 60%, and 15%, respectively) [16], and a large study of 1,033 professional ice hockey players revealed that athletes wearing mouthguards had significantly lower severity of symptoms compared to those who did not ($p < 0.01$) [15]. In two experiments assessing upper limb injuries (wrist and shoulder), wrist guards or external joint supports effectively protected ice and snow participants from wrist injuries [6, 7]. Wrist injuries are common among skiers, hence wrist protectors have been developed to reduce injury risk, with specific wrist protector designs showing significant protective effects [7]. Rønning et al. found that wrist injuries significantly decreased in a group using wrist guards, by randomly assigning snowboarders to an intervention or control group.

Despite the significant preventive effects shown, potential biases exist. An undeniable fact is that almost all ice rinks and ski resorts require participants to wear protective equipment, corroborating our study results. Further research is needed to explore which aspects of protective equipment may carry potential risks.

Additionally, numerous studies on policy and rule changes have confirmed their effectiveness in preventing injuries among ice hockey players [10, 22, 47, 48, 49]. For instance, in several studies evaluating the impact of prohibiting body checking, both injuries and penalties decreased, along with a reduction in injury rates. Regnier et al. found that in leagues where body checking was allowed (ages 11–12), players faced a higher risk of severe injuries. It was observed that in Ontario and Quebec, in leagues allowing body checking (ages 14–15), players had higher injury rates compared to leagues where body checking was not permitted. The increased injury risk in leagues allowing body checking suggests that changes to body checking rules can be beneficial in protecting players. From a player development perspective, introducing body checking at an earlier age can be highly beneficial for the growth of adolescents, eliminating the career risks brought by injuries[47]. Black et al. noted that in non-elite Canadian ice hockey games [10], the abolition of body checking policy led to a relative reduction of 50% in injury rates and 64% in concussion rates among Alberta's 11 and 12-year-old ice hockey players [12], with a threefold decrease in injury and concussion risks [10]. Slaney pointed out that mandatory wrist guard wearing in schools can effectively reduce the risk of upper limb fractures. However, the effectiveness of implementing these policies outside the school environment remains unknown [44].

Given this, changes in policy and rules fundamentally alter the culture of a sport, maintaining the common interests of stakeholders. These findings corroborate our study, suggesting that policy and rule interventions have effective potential for preventing injuries in ice and snow sports. Therefore, it's necessary to develop sports rules and policies from various dimensions to ensure the common interests of stakeholders, which is crucial for ensuring the sustainable development and nurturing of talent in these sports.

4.3 Strengths and Limitations

In the scholarly assessment of literature quality within our study, we adhered to the AMSTAR 2 criteria, a rigorous standard for evaluating research bias. According to this framework, a study is deemed to exhibit a low risk of bias if it fulfills at least 7 out of 7 critical items without major methodological shortcomings. Conversely, studies scoring below 5 or those with significant flaws are classified as high-risk for bias. In our meta-analysis, only 7 studies were adjudged as low-risk, with 4 rated as moderate-risk, 3 as high-risk, and 1 as very low-risk. This categorization highlights the methodological diversity and potential issues of internal validity in the sampled studies.

Moreover, the issue of external validity is salient. The included studies encompassed a broad spectrum of participants across various age groups and skill levels, potentially limiting the extrapolation of our findings to elite athletic contexts. This limitation underscores the need for future empirical investigations in this area. Notably, the incorporation of case-control and prospective cohort studies may have attenuated the overall robustness of the evidence. Our subgroup analyses, despite being meticulously conducted, contended with variability in intervention approaches, study designs, and participant demographics. Our overarching aim was to collate an extensive array of reliable evidence, predominantly through randomized studies, to inform injury prevention strategies in ice and snow sports. This endeavor entailed synthesizing a diverse corpus of data, confronting the inherent complexities of integrating varied methodologies and participant cohorts. While this strategy yields an expansive understanding, it also necessitates a nuanced interpretation of the results, considering the varied degrees of bias and potential constraints in generalizing outcomes across different populations and sporting disciplines.

The dynamic and multifaceted nature of sports injury prevention mandates adaptability to real-world contexts and diverse frameworks [52]. Current research in ice and snow sports injury prevention predominantly addresses scenario-specific solutions, yet there is a burgeoning need to reinforce practical applications. Given the unique and evolving nature of implementation scenarios, strategies tailored to a singular context may not suffice. Future research should pivot towards elucidating the underpinnings of effective methods in dynamic scenarios, identifying key elements that enhance the impact of these interventions. Emphasizing process-oriented approaches over singular solutions, the focus should be on the comprehensive efficacy of intervention programs and their implementation trajectories. A practical, scalable, and adaptable intervention program, when applied with creativity and flexibility, can provide a robust theoretical and practical foundation for designing and implementing context-specific strategies [53]. The focal point of research in preventing injuries in ice and snow sports should be to offer actionable, relevant preventive insights to coaches, practitioners, and participants, aiding them in developing more efficacious preventive measures. While our study primarily explored the efficacy of multifaceted intervention measures, future research should delve into understanding the intrinsic mechanisms and situational applicability of these interventions, as well as concentrate on the intricacies of the injury prevention process. Such an approach will enable the customization of interventions to specific contexts, thereby enhancing their overall effectiveness and applicability.

5 CONCLUSION

This study included randomized controlled trials, case-control, and prospective cohort studies on the prevention of injuries in ice and snow sports. By synthesizing 27 data samples from 15 studies, various intervention measures were found to effectively reduce the injury risk among ice and snow sports participants by 50% (RR = 0.50, 95% CI 0.41–0.62). Multifaceted intervention measures reduced the risk by 48% (RR = 0.52, 95% CI 0.42–0.63), with educational training reducing it by 50% (RR = 0.50, 95% CI 0.34–0.73), educational videos by 47% (RR = 0.53, 95% CI 0.34–0.81), protective equipment by 36% (RR = 0.64, 95% CI 0.46–0.87), and policy and rules changes by 72% (RR

= 0.28, 95% CI 0.16–0.49). The decrease in injury risk contributes to reducing the subsequent economic costs and social cost-benefit of treatment.

Recognizing that sports injuries constitute a formidable impediment to the enthusiasm and well-being of participants in ice and snow sports, and considering their substantial economic implications, our study's findings are firmly rooted in evidence-based research. The prevalence of injuries in these sports settings can be effectively mitigated, at least partially, through strategic intervention measures such as comprehensive educational training programs. The proactive promotion and implementation of these evidence-based interventions stand to confer significant additional benefits. Thus, it is imperative to advocate for and disseminate such evidence-based intervention measures within the realm of ice and snow sports. The future of these sports is inextricably linked to the development and adoption of interventions that are not only easy to implement but also cost-effective. Such injury prevention programs are crucial in safeguarding the health and fostering the continued participation of athletes, thereby ensuring the sustainable growth and vitality of these sporting disciplines. The integration of these measures into standard practice will not only enhance the safety and enjoyment of participants but also contribute to the overall economic efficiency of these sports by reducing the costs associated with sports-related injuries.

Declarations

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Authors’ contributions

The authors confrm contribution to the paper as follows: Fan and Min conceived the idea of the paper. Fan and Yang searched, screened articles and collected data. Fan and Ma did the quality assessment; Fan and He conducted the analysis, supervised by Min; and , Yang and Yao. The paper writing, supervised and edited by He, Yang, Ma and Yao. All authors contributed to the article and approved the submitted version.

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Data availability

The datasets supporting the conclusions of this article are included within the article or contact the first author of this article to obtain the original data.The datasets generated during and/or analyzed during the current study are publicly available

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

All the authors declare that they have no conflict of interest.

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Figures

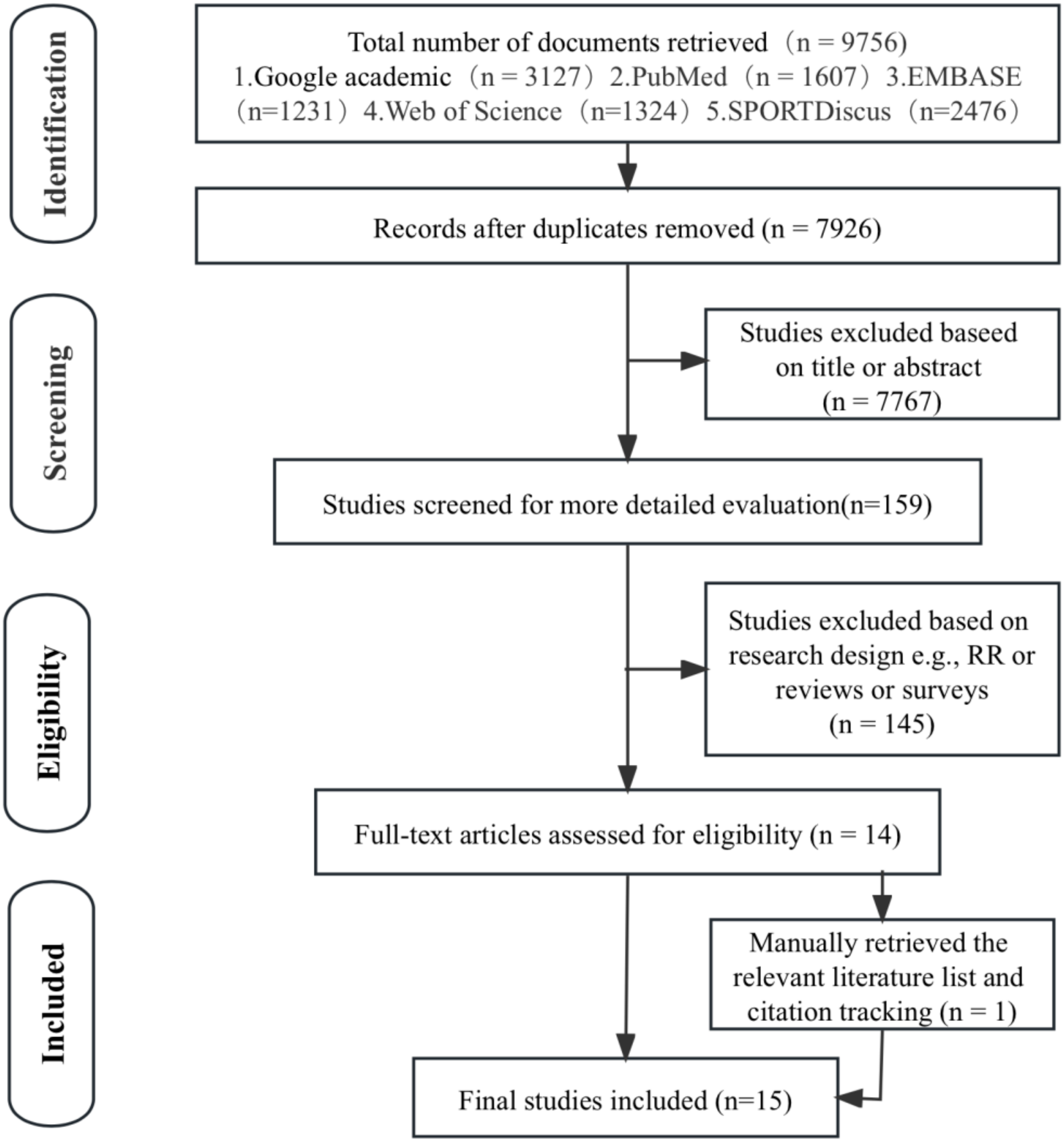


Figure 1

Flow chart of the study selection process.

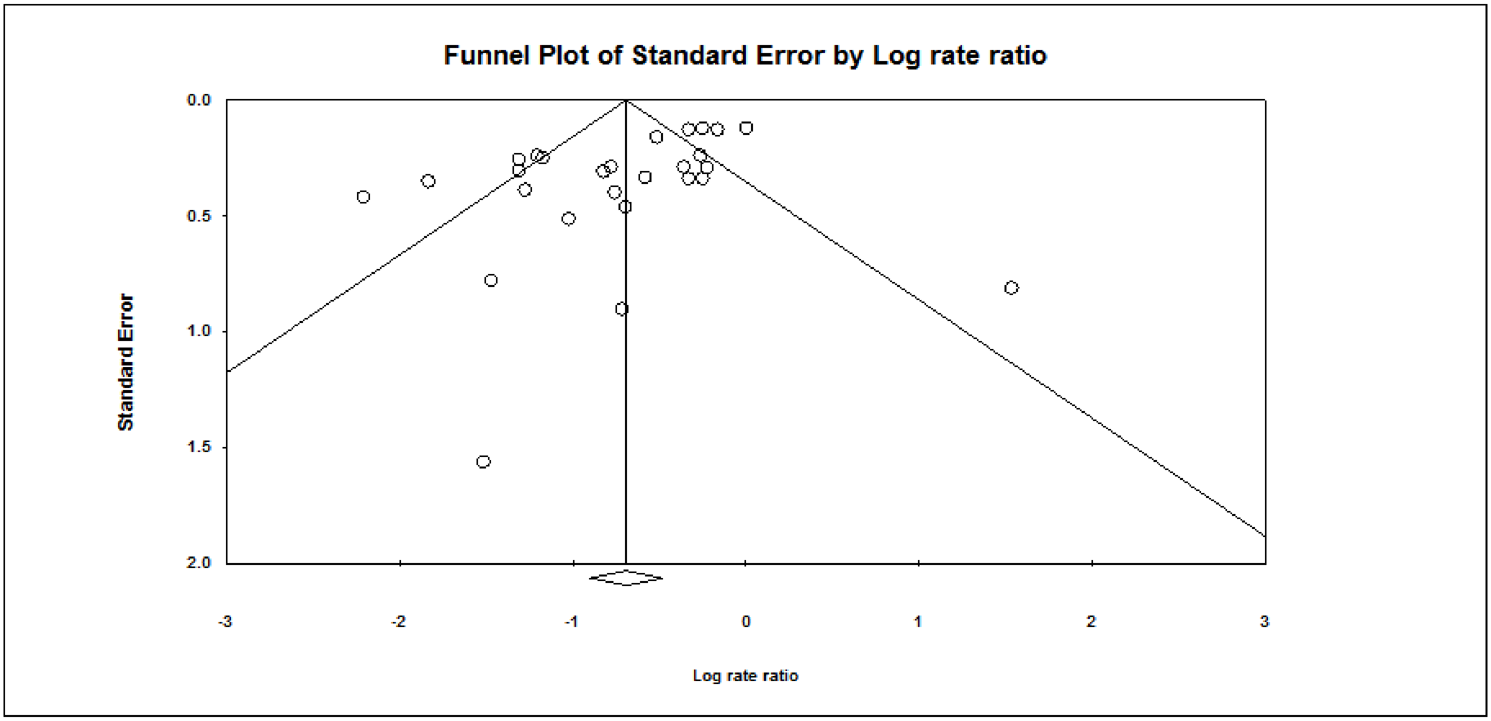
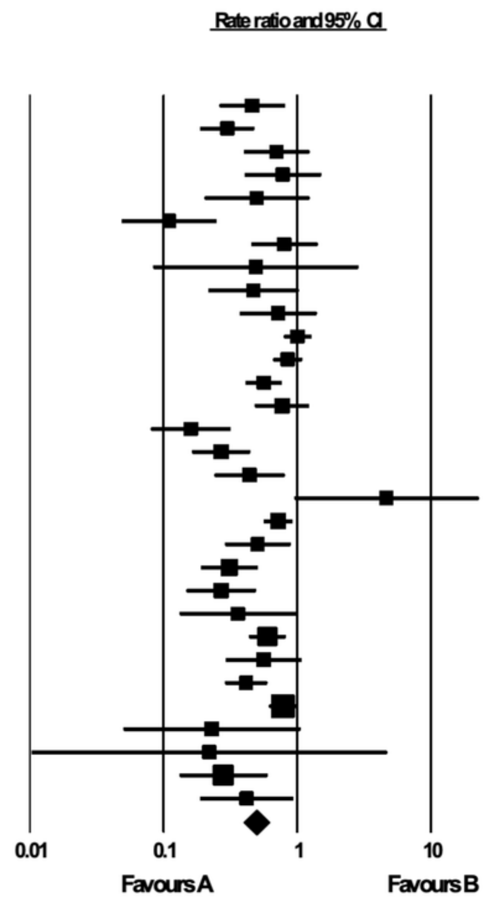


Figure 2

Publication bias funnel chart of the study sample.

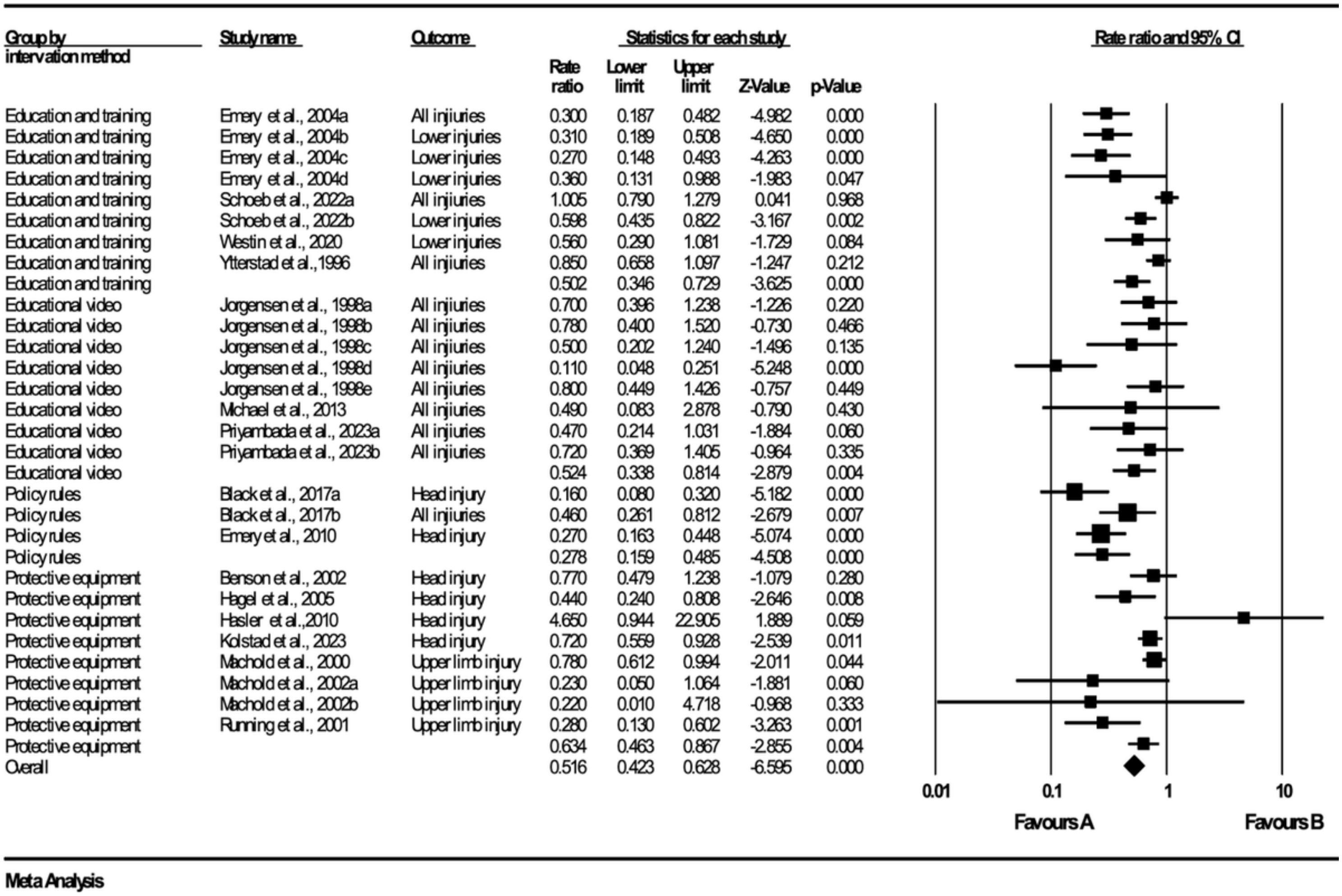
Group by Outcome	Study name	Outcome	Rate ratio	Lower limit	Upper limit	Z-Value	p-Value
			Statistics for each study				
All injiuries	Black et al., 2017b	All injiuries	0.460	0.261	0.812	-2.679	0.007
All injiuries	Emery et al., 2004a	All injiuries	0.300	0.187	0.482	-4.982	0.000
All injiuries	Jorgensen et al., 1998a	All injiuries	0.700	0.396	1.238	-1.226	0.220
All injiuries	Jorgensen et al., 1998b	All injiuries	0.780	0.400	1.520	-0.730	0.466
All injiuries	Jorgensen et al., 1998c	All injiuries	0.500	0.202	1.240	-1.496	0.135
All injiuries	Jorgensen et al., 1998d	All injiuries	0.110	0.048	0.251	-5.248	0.000
All injiuries	Jorgensen et al., 1998e	All injiuries	0.800	0.449	1.426	-0.757	0.449
All injiuries	Michael et al., 2013	All injiuries	0.490	0.083	2.878	-0.790	0.430
All injiuries	Priyambada et al., 2023a	All injiuries	0.470	0.214	1.031	-1.884	0.060
All injiuries	Priyambada et al., 2023b	All injiuries	0.720	0.369	1.405	-0.964	0.335
All injiuries	Schoeb et al., 2022a	All injiuries	1.005	0.790	1.279	0.041	0.968
All injiuries	Ytterstad et al.,1996	All injiuries	0.850	0.658	1.097	-1.247	0.212
All injiuries			0.562	0.408	0.773	-3.542	0.000
Head injury	Benson et al., 2002	Head injury	0.770	0.479	1.238	-1.079	0.280
Head injury	Black et al., 2017a	Head injury	0.160	0.080	0.320	-5.182	0.000
Head injury	Emery et al., 2010	Head injury	0.270	0.163	0.448	-5.074	0.000
Head injury	Hagel et al., 2005	Head injury	0.440	0.240	0.808	-2.646	0.008
Head injury	Hasler et al.,2010	Head injury	4.650	0.944	22.905	1.889	0.059
Head injury	Kolstad et al., 2023	Head injury	0.720	0.559	0.928	-2.539	0.011
Head injury			0.506	0.287	0.893	-2.350	0.019
Lower injuries	Emery et al., 2004b	Lower injuries	0.310	0.189	0.508	-4.650	0.000
Lower injuries	Emery et al., 2004c	Lower injuries	0.270	0.148	0.493	-4.263	0.000
Lower injuries	Emery et al., 2004d	Lower injuries	0.360	0.131	0.988	-1.983	0.047
Lower injuries	Schoeb et al., 2022b	Lower injuries	0.598	0.435	0.822	-3.167	0.002
Lower injuries	Westin et al., 2020	Lower injuries	0.560	0.290	1.081	-1.729	0.084
Lower injuries			0.415	0.288	0.599	-4.701	0.000
Upper limb injury	Machold et al., 2000	Upper limb injury	0.780	0.612	0.994	-2.011	0.044
Upper limb injury	Machold et al., 2002a	Upper limb injury	0.230	0.050	1.064	-1.881	0.060
Upper limb injury	Machold et al., 2002b	Upper limb injury	0.220	0.010	4.718	-0.968	0.333
Upper limb injury	Running et al., 2001	Upper limb injury	0.280	0.130	0.602	-3.263	0.001
Upper limb injury			0.418	0.186	0.942	-2.105	0.035
Overall			0.489	0.395	0.606	-6.553	0.000



Meta Analysis

Figure 3

The results of the meta-analysis were included.



Group by intervation method	Study name	Outcome	Rate ratio	Lower limit	Upper limit	Z-Value	p-Value
Education and training	Emery et al., 2004a	All injiuries	0.300	0.187	0.482	-4.982	0.000
Education and training	Emery et al., 2004b	Lower injuries	0.310	0.189	0.508	-4.650	0.000
Education and training	Emery et al., 2004c	Lower injuries	0.270	0.148	0.493	-4.263	0.000
Education and training	Emery et al., 2004d	Lower injuries	0.360	0.131	0.988	-1.983	0.047
Education and training	Schoeb et al., 2022a	All injiuries	1.005	0.790	1.279	0.041	0.968
Education and training	Schoeb et al., 2022b	Lower injuries	0.598	0.435	0.822	-3.167	0.002
Education and training	Westin et al., 2020	Lower injuries	0.560	0.290	1.081	-1.729	0.084
Education and training	Ytterstad et al., 1996	All injiuries	0.850	0.658	1.097	-1.247	0.212
Education and training			0.502	0.346	0.729	-3.625	0.000
Educational video	Jorgensen et al., 1998a	All injiuries	0.700	0.396	1.238	-1.226	0.220
Educational video	Jorgensen et al., 1998b	All injiuries	0.780	0.400	1.520	-0.730	0.466
Educational video	Jorgensen et al., 1998c	All injiuries	0.500	0.202	1.240	-1.496	0.135
Educational video	Jorgensen et al., 1998d	All injiuries	0.110	0.048	0.251	-5.248	0.000
Educational video	Jorgensen et al., 1998e	All injiuries	0.800	0.449	1.426	-0.757	0.449
Educational video	Michael et al., 2013	All injiuries	0.490	0.083	2.878	-0.790	0.430
Educational video	Priyambada et al., 2023a	All injiuries	0.470	0.214	1.031	-1.884	0.060
Educational video	Priyambada et al., 2023b	All injiuries	0.720	0.369	1.405	-0.964	0.335
Educational video			0.524	0.338	0.814	-2.879	0.004
Policy rules	Black et al., 2017a	Head injury	0.160	0.080	0.320	-5.182	0.000
Policy rules	Black et al., 2017b	All injiuries	0.460	0.261	0.812	-2.679	0.007
Policy rules	Emery et al., 2010	Head injury	0.270	0.163	0.448	-5.074	0.000
Policy rules			0.278	0.159	0.485	-4.508	0.000
Protective equipment	Benson et al., 2002	Head injury	0.770	0.479	1.238	-1.079	0.280
Protective equipment	Hagel et al., 2005	Head injury	0.440	0.240	0.808	-2.646	0.008
Protective equipment	Hasler et al.,2010	Head injury	4.650	0.944	22.905	1.889	0.059
Protective equipment	Kolstad et al., 2023	Head injury	0.720	0.559	0.928	-2.539	0.011
Protective equipment	Machold et al., 2000	Upper limb injury	0.780	0.612	0.994	-2.011	0.044
Protective equipment	Machold et al., 2002a	Upper limb injury	0.230	0.050	1.064	-1.881	0.060
Protective equipment	Machold et al., 2002b	Upper limb injury	0.220	0.010	4.718	-0.968	0.333
Protective equipment	Running et al., 2001	Upper limb injury	0.280	0.130	0.602	-3.263	0.001
Protective equipment			0.634	0.463	0.867	-2.855	0.004
Overall			0.516	0.423	0.628	-6.595	0.000

Figure 4

combined effect of multi-component intervention on injury rate of participants.

Supplementary Files

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