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Neuromuscular Training for Sports Injury Prevention: A Systematic Review

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ABSTRACT

HÜBSCHER, M., A. ZECH, K. PFEIFER, F. HÄNSEL, L. VOGT, and W. BANZER. Neuromuscular Training for Sports Injury Prevention: A Systematic Review. *Med. Sci. Sports Exerc.*, Vol. 42, No. 3, pp. 413–421, 2010. **Purpose**: The aim of this systematic review was to assess the effectiveness of proprioceptive/neuromuscular training in preventing sports injuries by using the best available evidence from methodologically well-conducted randomized controlled trials and controlled clinical trials without randomization. **Methods**: Two independent researchers performed a literature search in various electronic databases and reference lists. The reviewers independently assessed trials for inclusion criteria and methodological quality and extracted the data. Focusing on studies of high methodological quality, relative risks (RR) and 95% confidence intervals (CI) were used to estimate treatment effects. **Results**: From a total of 32 relevant studies, 7 methodologically well-conducted studies were considered for this review. Pooled analysis revealed that multi-intervention training was effective in reducing the risk of lower limb injuries (RR = 0.61, 95% CI = 0.49–0.77, $P < 0.01$), acute knee injuries (RR = 0.46, 95% CI = 0.28–0.76, $P < 0.01$), and ankle sprain injuries (RR = 0.50, 95% CI = 0.31–0.79, $P < 0.01$). Balance training alone resulted in a significant risk reduction of ankle sprain injuries (RR = 0.64, 95% CI = 0.46–0.9, $P < 0.01$) and a nonsignificant risk reduction for injuries overall (RR = 0.49, 95% CI = 0.13–1.8, $P = 0.28$). Exercise interventions were more effective in athletes with a history of sports injury than in those without. **Conclusion**: On the basis of the results of seven high-quality studies, this review showed evidence for the effectiveness of proprioceptive/neuromuscular training in reducing the incidence of certain types of sports injuries among adolescent and young adult athletes during pivoting sports. Future research should focus on the conduct of comparative trials to identify the most appropriate and effective training components for preventing injuries in specific sports and populations. **Key Words:** ANKLE SPRAIN INJURIES, KNEE INJURIES, INJURY RISK, PROPRIOCEPTIVE TRAINING, BALANCE TRAINING

Epidemiological studies have shown that sports and recreation injuries constitute a major public health burden in many developed countries (5,11,32). According to the German National Health Survey, 3.1% of all adults or rather 5.6% among those engaging in regular recreational physical activity received medical treatment for nonfatal sports injuries during the preceding year (52,53). Sports injuries are therefore ranked as the second most common type of injury after domestic accidents (3.7%), the total annual incidence of injuries being about 2 million (52). The most common sports injuries (60%) are sprains, dislocations, and ligament ruptures occurring at the knee and ankle as well as at the hand, elbow, and shoulder (11,24, 50,52). Particularly, severe injuries such as anterior cruciate ligament (ACL) ruptures or ankle sprains are often associated with increased morbidity (e.g., early development of joint osteoarthritis) and long-term disability (4,10,14,16).

In view of appropriate intervention strategies, the prevention of injuries must be considered a primary goal. On the basis of previous research, it is hypothesized that proprioceptive and neuromuscular abilities in particular have a certain impact on injury risk (29,47). In this context, recent studies have shown positive effects of distinct exercise programs targeting the enhancement of proprioceptive, neuromuscular, and sensorimotor abilities (14,42,51). However, the implementation of evidence-based practice into injury prevention is complicated because of the following reasons. First, recent studies examining proprioceptive/neuromuscular training (PT/NT) interventions for prevention of sports injuries show a large variety of exercises. Whereas in most

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studies balance exercises on stable or unstable platforms with and without perturbations of postural control were used, some authors described neuromuscular training as multi-intervention programs with a combination of balance, weight, plyometric, agility, and sport-specific exercises (20,27,54). Second, the methodological quality of published studies reveals substantial differences in key criteria concerned predominantly with internal validity. Consequently, systematic reviews using methodological quality assessment are needed to determine the effectiveness of PT/NT in preventing sports injuries. Previous reviews either assessed the effectiveness of various injury prevention methods such as different insoles, external joint supports, and training programs (1) or concentrated solely on specific types of injuries, such as ACL ruptures (26) or ankle ligament injuries (22).

The aim of this systematic review of randomized controlled trials (RCT) and controlled clinical trials without randomization (CT) was to assess the effectiveness of PT/NT in preventing sports injuries by using the best available evidence from methodologically well-conducted trials. Recent studies that were not yet considered in previous systematic reviews were incorporated.

METHODS

Literature search. Two independent reviewers (MH and AZ) conducted a computerized search for articles published in English and German between the years 1966 and October 2008 in the following databases: Cochrane Bone, Joint and Muscle Trauma Group Register and Cochrane Controlled Trials Register, MEDLINE, EMBASE, PEDro, and SCOPUS. Keywords used included "neuromuscular," "sensorimotor," "kinaesthetic," "proprioceptive," "prevention," "injury/ies," "training," "exercise," "program," "wobble board," "plyometric," "balance," "jumping," "postural control," "perturbation," "balance board," "proprioception," "coordination," and "jump." These keywords were used separately and in combination. Furthermore, reference lists of all retrieved articles, and relevant reviews were manually checked for additional studies.

Study selection. The identified studies were initially screened by the two independent reviewers for title, abstract, and keywords to determine whether they met the following selection criteria: RCT or CT; athletes with and without previous injury; and only the intervention group received PT/NT, and PT/NT had to be compared with no treatment or other interventions. Each study was required to evaluate injury incidence as an outcome. Articles that met the selection criteria as well as articles whose abstracts were imprecise concerning the selection criteria were considered for full text analysis.

Assessment of methodological quality. The methodological quality of the studies was independently assessed by the two reviewers (MH and AZ) using a modified version of the criteria list proposed by van Tulder et al. (58). Accordingly, the following nine criteria were evaluated: a) randomization method, b) concealed treatment allocation, c) baseline similarity of study groups regarding the most important prognostic variables, d) blinding of assessors, e) cointerventions, f) compliance, g) dropout rate, h) timing of the outcome assessment, and i) intention-to-treat analysis. Adequate methods of randomization were, for instance, computer-generated random number table and use of sealed opaque envelopes. Methods of allocation using date of birth, date of admission, or alternation were not accepted as appropriate (58). Concealed treatment allocation had to be accomplished through random assignment generated by an independent person not responsible for determining the eligibility of the subjects (i.e., centralized randomization). Compliance to the interventions, determined by training diaries or objective monitoring, could not be less than 75%. The dropout rate was considered acceptable up to 25% for follow-up <6 months and up to 30% for follow-up >6 months. The timing of outcome assessment had to be identical for all study groups and for all outcome measurements. The nine criteria for the assessment of the methodological quality were scored as positive ("yes"), negative ("no"), or unclear ("don't know") in case of inadequate reporting. Each criterion that was scored positive contributed 1 point to the summary quality score, ranging from 0 to 9 points. Studies were considered to be of high methodological quality if they adequately fulfilled at least 50% or five of nine of the quality criteria (58). Accordingly, high-quality studies were used as primary (best) evidence with respect to the purpose of the present review, whereas studies of lower methodological quality (summary quality score <5) were only included in the absence of high-quality trials (secondary evidence). The reviewers pilot tested the methodological quality assessment on a subset of five included articles for agreement on a common interpretation of the items and their operationalization. The interrater reliability of the quality assessment was not evaluated statistically during the pilot testing phase.

Data extraction. Data extraction from the selected studies was performed by two independent reviewers (MH and AZ) using standard extraction forms. The data of interest included study design and methods, subject characteristics, interventions, and results. To improve agreement in the data extraction, the reviewers pilot tested the extraction form on a subset of five included articles by identifying the relevant study characteristics and unnecessary or missing data with respect to the aim of our review.

Disagreements. Disagreements between the reviewers regarding the selection of studies, the assessment of methodological quality, and the data extraction were solved by consensus. Persisting disagreements were discussed in a consensus meeting of all coauthors to make the final decision.

Data analysis. To assess the preventive effects of PT/NT programs, incidence rates, relative risks (RR), and 95% confidence intervals (CI) were extracted as appropriate to the data. The results of comparable studies were pooled by using a fixed effects model. Heterogeneity was examined using the Cochran Q test and the I^2 statistic, which is the percentage of total variation across studies that is due to heterogeneity rather than chance (28). We considered P values of less than 0.1 as indicating significant heterogeneity and I^2 values of 25%, 50%, and 75% as corresponding to low, moderate, and high heterogeneity (28). When heterogeneity existed, a random effects model was additionally used. Statistical analyses were performed using the MIX meta-analytical software (version 1.7) (3). The threshold for statistical significance was set to $P < 0.05$.

RESULTS

Literature Search

The search strategy retrieved 32 relevant trials for further analysis. Eight studies were excluded, of which five studies lacked controls (2,7,31,36,40), one study had an inadequate description of interventions (33), and two studies did not evaluate the injury incidence (39,48). Consequently, 17 RCT and 7 CT met the selection criteria and were considered for methodological quality assessment.

Methodological Quality

Table 1 shows details of the methodological quality assessment of the 24 studies. The average summary quality score was 3 (range = 1–8) out of 9. The method of randomization was adequate in 4 RCT, whereas 13 RCT did not report the method of randomization. The treatment allocation was adequately concealed in 4 RCT and unclear in 13 RCT. The assessors were blinded for the group allocation in 4 studies and not blinded in 7 studies, and 13 studies did not describe the blinding status. The compliance with exercise interventions was adequate in 6 trials, insufficient in 4 trials, and not stated in 14 trials.

Finally, seven RCT of high methodological quality adequately fulfilled the defined inclusion criteria (18,19,21,35,41,43,56). The average summary quality score of these studies was 6 (range = 5–8). The main characteristics of the included studies are presented in Table 2.

Description of Included Studies

Two studies were conducted in Canada (18,19), two studies in Norway (41,56), one study in Finland (43), and two studies in the United States (21,35).

The average sample size comprised 1078 subjects (range = 114–2020) and was based on *a priori* power analyses in all studies except one (21). All trials included adolescent and young adult athletes aged 12 to 24 yr. Participants were regularly engaged in organized sports (school sports and club sports), practicing basketball (18,19,35), volleyball (18), soccer (18,21,35,56), and team handball (41) as well as hockey (18) and floorball (43).

The exercises included balance training in three studies (18,19,35), and four studies used multi-intervention programs comprising balance training, agilities, stretching, plyometrics, running exercises, cutting, and landing technique as well as strength training (21,41,43,56). These exercises were performed by all intervention groups in addition to their usual participation in high school or club sports, whereas control subjects only participated in usual school or club sports.

Sports injury incidence was expressed as injury rates per 1000 participation hours in four studies (19,41,43,56),

TABLE 1. Methodological quality assessment.

Study	Quality Score	Quality Criteria a	b	c	d	e	f	g	h	i
Caraffa et al. (8)	1	N	N	DK	DK	N	DK	DK	Y	N
Cumps et al. (13)	4	N	N	Y	N	Y	DK	Y	Y	N
Emery et al. (18)	6	Y	DK	Y	N	Y	DK	Y	Y	Y
Emery et al. (19)	6	Y	Y	Y	N	Y	N	Y	Y	DK
Engebretsen et al. (20)	3	DK	DK	DK	N	N	N	Y	Y	Y
Gilchrist et al. (21)	5	DK	DK	Y	N	N	Y	Y	Y	Y
Heidt et al. (25)	2	DK	DK	DK	Y	N	DK	DK	Y	DK
Hewett et al. (27)	2	N	N	DK	DK	N	DK	Y	Y	N
Mandelbaum et al. (34)	1	N	N	DK	N	N	DK	DK	Y	N
McGuine and Keene (35)	6	DK	DK	Y	DK	Y	Y	Y	Y	Y
Mohammadi (37)	3	DK	DK	Y	DK	Y	DK	Y	DK	DK
Olsen et al. (41)	6	DK	Y	DK	Y	N	Y	Y	Y	Y
Pasanen et al. (43)	8	Y	Y	Y	Y	N	Y	Y	Y	Y
Petersen et al. (45)	1	N	N	DK	DK	N	DK	DK	Y	N
Petersen et al. (44)	3	N	N	DK	DK	Y	DK	Y	Y	N
Pfeiffer et al. (46)	3	N	N	DK	DK	Y	Y	DK	Y	N
Söderman et al. (54)	3	DK	DK	DK	DK	Y	Y	N	Y	DK
Stasinopoulos (55)	4	Y	DK	DK	DK	Y	DK	Y	Y	DK
Steffen et al. (56)	5	DK	Y	DK	Y	N	N	Y	Y	Y
Tropp et al. (57)	2	DK	DK	DK	DK	Y	N	DK	Y	N
Verhagen et al. (59)	3	DK	DK	Y	N	Y	DK	N	Y	DK
Wedderkopp et al. (61)	1	DK	DK	DK	DK	DK	DK	DK	Y	DK
Wedderkopp et al. (62)	2	DK	DK	DK	DK	DK	DK	DK	Y	Y
Wester et al. (63)	3	DK	DK	DK	DK	Y	DK	Y	Y	DK

Maximum obtainable quality score = 9 points.

a, acceptable method of randomization; b, concealed treatment allocation; c, similar group values at baseline; d, blinded assessor; e, avoided or similar cointerventions; f, acceptable compliance; g, acceptable dropout rate; h, similar timing of the outcome assessment in all groups; i, intention-to-treat analysis; Y, yes; N, no; DK, don't know.

TABLE 2. Included studies.

Study and Design	Participants	Interventions	Program Details	Outcomes
Emery et al. (18); cluster RCT	114 physical education students (50% male) 14–19 yr; dropouts = 10.2%	Balance training (wobble board)	In-season home exercise program more than 6 months, each with 20 min, seven times a week for 6 wk, then once a week during the remainder of the season	All sports injuries
Emery et al. (19); cluster RCT	920 basketball players (50.4% male) 12–18 yr; dropout = 1.2%	Balance training (sport-specific, wobble board)	In-season and of-season program more than 12 months: 1) warm-up component (sport-specific) for practice sessions, each with 5 min, five times a week; and 2) home exercise program (wobble board), each with 20 min	All sports injuries
Gilchrist et al. (21); cluster RCT	1435 female soccer players 19.9 yr (mean); dropout = 12%	Multi-intervention training program: running exercises, stretching, strengthening, plyometrics, agilities	In-season warm-up program, before practice, each with 20 min, three times a week for 12 wk	Knee injuries
McGuine and Keene (35); cluster RCT	765 basketball and soccer player (31.6% male) 16.5 ± 1.2 yr (mean ± SD); dropout = 1.4%	Balance training (single-leg stance, balance board)	Preseason and in-season program, before or after practice, each with 10 min, five times a week for 4 wk before the start of the season, then three times a week throughout the season	Ankle sprains
Olsen et al. (41); cluster RCT	1837 handball players (13.7% male) 15–17 yr; dropout = 2.5%	Multi-intervention training program: running exercises, cutting and landing technique training, balance training, strength and power training	In-season warm-up program more than 8 months, before practice, each with 15–20 min, every training session for 15 consecutive sessions, then once a week during the remainder of the season	1) Acute ankle and knee injuries; 2) lower and upper limb injuries; and 3) injuries overall
Pasanen et al. (43); cluster RCT	457 female floorball players 23.8 ± 4.9 yr (mean ± SD); dropout = 3.8%	Multi-intervention training program: running techniques, balance training, plyometrics, strengthening exercises, stretching	In-season warm-up program, before practice, each with 20–30 min, two to three times a week for 16 wk, then once a week during the remainder of the season	1) Acute leg injuries and 2) all leg injuries
Steffen et al. (56); cluster RCT	2020 female football players 13–17 yr; dropout = 2.4%	Multi-intervention training program: core stability exercises, balance training, plyometrics, strength training	Preseason (2 months) and in-season (6 months) warm-up program, before practice, each 15–20 min, every training session for 15 consecutive sessions, then once a week during the remainder of the season	All sports injuries

injury rates per 1000 athlete exposures in two studies (21,35), and cumulative incidence in one study (18). Four studies reported on sport injuries overall, that is, all injuries occurring during sports participation, including sprains, contusions, fractures, and strains of the feet, ankle, knee, finger, low back, and shoulder (18,19,41,56). One study registered lower extremity injuries, including muscle strains, ankle sprains, knee ligament sprains, and meniscus tears (43). Another study monitored knee injuries, including medial collateral ligament injuries (either in isolation or occurring with meniscal or cartilage injury), isolated meniscal or cartilage injury, and ACL injuries (21). The study by McGuine and Keene (35) concentrated solely on ankle sprain injuries.

Emery et al. (18) additionally assessed balance ability under static and dynamic conditions. For this purpose, the subjects completed, with their eyes closed, a timed single limb stance on the floor and a timed dynamic single limb stance on an Airex balance pad. The tests were closely related to the training interventions that also included unipedal standing balance exercises with eyes closed on a wobble board. The balance tests were performed at baseline and biweekly for 6 wk, while the change from baseline to 6-wk follow-up was defined as the primary outcome. Balance ability was not measured at the end of the 6-month study period.

Injury Incidence

Balance training. Emery et al. (18) demonstrated a significantly lower incidence of all sports injuries in the intervention group as compared with the control subjects (RR = 0.2, 95% CI = 0.05–0.88). In comparison with the control subjects, the intervention was more effective for participants with a history of previous injury (RR = 0.13, 95% CI = 0.02–1.0) than for those without previous injury (RR = 0.28, 95% CI = 0.03–2.43). Subgroup analyses revealed a significant reduction in ankle injuries through balance training (RR = 0.14, 95% CI = 0.18–1.13). In addition, subjects in the intervention groups showed significant improvements in static and dynamic balance ability (after 6 wk) in comparison with the control group.

Emery et al. (19) showed significant reductions in the number of acute sports injuries induced by balance training when compared with controls (RR = 0.71, 95% CI = 0.5–0.99). However, subgroup analyses only found insignificant effects with respect to 1) all injury (RR = 0.80, 95% CI = 0.57–1.11), 2) injuries of the lower extremity (RR = 0.83, 95% CI = 0.57–1.19), and 3) ankle injuries (RR = 0.71, 95% CI = 0.45–1.13). Furthermore, no significant group differences in the severity of injuries were observed.

The study by McGuine and Keene (35) reported that the incidence of ankle sprains was significantly lower in the intervention group when compared with the control subjects (RR = 0.62, 95% CI = 0.38–1.02). The ankle sprain incidence among athletes with a history of a sprain was significantly reduced in the intervention groups as compared with the control group (RR = 0.56, 95% CI = 0.33–0.95). Although in athletes without previous ankle sprain the training program appeared to reduce the injury risk when compared with controls (RR = 0.55, 95% CI = 0.28–1.08), the results did not achieve statistical significance.

Pooling of RR was possible for sports injuries overall in two studies (18,19), revealing a statistically nonsignificant RR of 0.30 (95% CI = 0.14–0.65, $P < 0.08$) in favor of balance training. However, significant heterogeneity was detected ($P = 0.07$, $I^2 = 66\%$). The corresponding random effects estimation showed a nonsignificant RR of 0.49 (95% CI = 0.13–1.8, $P = 0.28$) in favor of balance training (Fig. 1A). Furthermore, pooling of RR was possible for ankle sprain injuries in three studies (18,19,35), showing a statistically significant RR of 0.64 (95% CI = 0.46–0.9, $P < 0.01$) in favor of balance training (Fig. 1B). Heterogeneity was not significant ($P = 0.33$, $I^2 = 11\%$).

Multi-intervention training. Gilchrist et al. (21) discovered nonsignificant trends in the overall (during practice/game/other) ACL injury risk and significant reductions in the risk of ACL injuries during practice. No ACL injuries occurred in the intervention group compared with six in the control group (injury rates/1000 athlete exposures = 0.000 vs 0.148, $P = 0.014$). Among athletes with a history of previous ACL injury, no intervention athlete suffered a noncontact ACL injury compared with four in the control group (injury rates/1000 athlete exposures = 0.000 vs 0.076, $P = 0.046$). No significant group differences were found in athletes without previous ACL injuries (injury rates/1000 athlete exposures = 0.057 vs 0.113, $P = 0.356$).

Olsen et al. (41) demonstrated significantly fewer injured athletes in the intervention group than that in the control group for injuries overall (RR = 0.49, 95% CI = 0.36–0.68), lower limb injuries (RR = 0.51, 95% CI = 0.36–0.73), acute knee injuries (RR = 0.45, 95% CI = 0.25–0.81), and upper limb injuries (RR = 0.37, 95% CI = 0.20–0.69). Moreover, significant group differences in the distribution of injury severity could be observed, indicating that the training program reduced the number of injuries of moderate (RR = 0.33, 95% CI = 0.20–0.55) and major (RR = 0.43, 95% CI = 0.28–0.66) severity. Only insignificant effects were found when acute ankle injuries were analyzed separately (RR = 0.63, 95% CI = 0.45–1.09).

The study by Pasanen et al. (43) found that the overall risk of leg injury was significantly different between the groups, favoring the intervention (RR = 0.70, 95% CI = 0.52–0.92, $P = 0.016$). In addition, significantly fewer acute leg injuries occurred in the intervention group than in the control group (RR = 0.34, 95% CI = 0.20–0.57); but when injuries

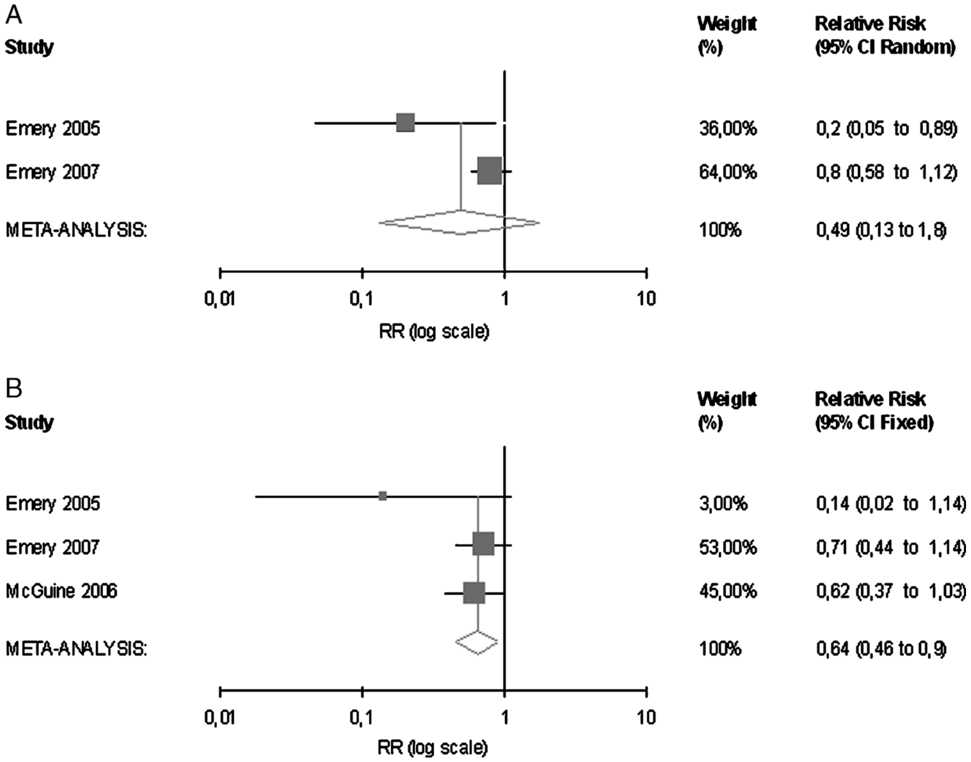

FIGURE 1—Effects of balance training on the RR of injuries overall (*A*) and ankle sprain injuries (*B*).

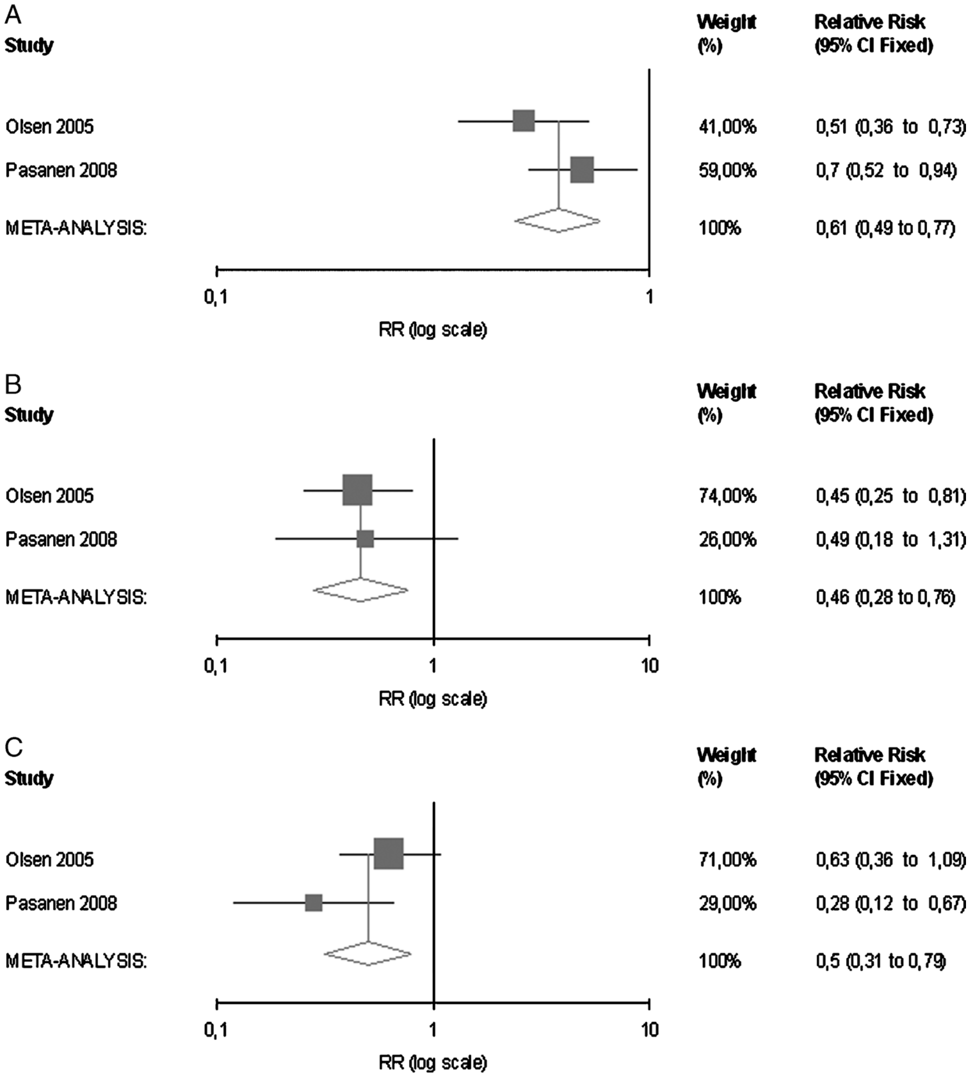

FIGURE 2—Effects of multi-intervention training on the RR of lower limb injuries (*A*), acute knee injuries (*B*), and ankle sprain injuries (*C*).

were analyzed by location, only the ankle injuries were significantly reduced (RR = 0.28, 95% CI = 0.12–0.67). No significant differences were found between the groups for acute knee injuries (RR = 0.49, 95% CI = 0.19–1.27).

In contrast to these studies, Steffen et al. (56) observed a difference neither in the overall injury rate between the intervention and the control groups (RR = 1.0, 95% CI = 0.8–1.2, $P = 0.94$) nor in the incidence of any type of injury. The authors argue that the compliance with the intervention was too low to induce the necessary training effects to reduce the injury risk.

The pooled results of two studies on lower limb injuries (41,43) showed a statistically significant RR of 0.61 (95% CI = 0.49–0.77, $P < 0.01$), favoring the intervention (Fig. 2A). Heterogeneity was not statistically significant ($P = 0.53$, $I^2 = 0\%$). Pooled analysis of these studies also found that multi-intervention training was effective in reducing the risk of acute knee injuries (RR = 0.46, 95% CI = 0.28–0.76, $P < 0.01$) and ankle sprain injuries (RR = 0.5, 95% CI = 0.31–0.79, $P < 0.01$) (Fig. 2B and C). Heterogeneity was not significant for lower limb injuries ($P = 0.19$, $I^2 = 43\%$), acute knee injuries ($P = 0.88$, $I^2 = 0\%$), or ankle sprain injuries ($P = 0.25$, $I^2 = 59\%$).

DISCUSSION

In the present systematic review, the effectiveness of PT/NT in preventing sports injuries was estimated by using the best available evidence from methodologically well-conducted trials. From a total of 32 relevant studies, seven trials of high methodological quality were identified and accordingly included in this review. One problem in the methodological quality assessment of the studies was the incomplete and inconsistent reporting on key criteria predominantly related to internal validity. Most studies lacked an appropriate report of the randomization method (54%), allocation concealment (54%), blinding status of outcome assessors (54%), and compliance with interventions (58%).

Consequently, the methodological quality might be underestimated because of insufficient reporting rather than to poor study design or poor methodological approach. It may reflect incomprehension of the importance of standardized trial reporting. Thus, with the objective of transparent reporting, consequent application of consensus publication guidelines is strongly needed. Respective guidelines have been provided for reporting of RCT as well as for trials using nonrandomized designs (15,38,60).

The present review and meta-analysis comprises data from seven high-quality RCT that were considered an appropriate basis for evidence-based guidance regarding sports injury prevention. Six of the seven studies demonstrated that balance exercises (three trials) or multi-intervention training programs (three trials) can be effective in reducing the incidence of specific types of sports injuries among adolescent and young adult athletes during pivoting sports, that is, basketball, volleyball, soccer, team handball, hockey, and floorball. The present review therefore contains studies on athletes that are largely representative for important high-risk populations (6,11,52). The results show that balance training was effective in reducing the risk of ankle sprain injuries by 36%. Individual studies found that balance exercises were more effective in athletes with a history of sports injury than in those without (18,35). Nevertheless, there was no evidence that balance training decreases the incidence of knee ligament injuries or upper extremity injuries or that it influences the severity of injuries (19).

The present meta-analysis revealed that multi-intervention training programs were effective in reducing the risk of lower limb injuries by 39%, the risk of acute knee injuries by 54%, and the risk of ankle sprain injuries by 50%. Individual studies suggested that multi-intervention training has a preventive effect on the risk of ACL injuries during practice (six ACL injuries in controls vs no injury in the intervention group), especially among those athletes with a history of ACL injury (21). Furthermore, a prevention effect was found for upper limb injuries and the severity of injuries (41). However, concerning the effects of multi-intervention training programs, it remains unclear whether and to what extent the various training components (e.g., balance, strength, or stretching exercises) may have contributed to the observed reduction in injury risk. The lack of significant effects of multi-intervention training reported by Steffen et al. (56) was most likely due to the poor compliance. In their study, the injury prevention program was used at 52% of all soccer training sessions. The authors discussed that such compliance might be insufficient to produce the necessary training effects to reduce the injury risk.

Our review revealed not enough evidence to allow conclusions to be drawn about the underlying mechanism of the observed protective effects of balance or multi-intervention training. Only one study additionally assessed balance ability under static and dynamic conditions and found significant improvements through balance training, respectively (18). Unfortunately, the authors did not report on statistical correlation and/or regression between changes in balance ability and injury incidence. Because it has been hypothesized that sports injury risk might be associated with parameters of proprioception, neuromuscular control, flexibility, jumping and landing skills, strength, and balance, exercise-based prevention strategies are primarily developed and applied to modify these risk factors (18). Therefore, future injury prevention studies should assess training-induced changes in these parameters as secondary outcome measurements to potentially identify causal relations between them and changes in the incidence of injuries. A better understanding of these associations might promote a more differentiated and mechanism-based application of training interventions to prevent specific injuries in specific sports populations.

Although all included studies evaluated injury incidence as a valid and clinically relevant outcome, the results of our review should be interpreted with respect to the variability of methods of injury data collection used. Although the definition of sports injuries and the classification of injury severity were almost identical across all studies (sports injury was basically defined as any injury occurring during sports practice that required medical attention and/or resulted in the loss of at least one competition or training session, and injury severity was classified according to the length of absence from competition and practice), the methods of data collection varied between self-report (18,43), team manager and/or physiotherapist report (19,41,56), or certified athletic trainer report (21,35). None of these studies provided quantitative data on the number of injuries that resulted in a physician consult and were diagnosed by clinical tests, imaging studies, or surgery. It was only in the study by Pasanen et al. (43) that an ACL injury had to be confirmed by magnetic resonance imaging, arthroscopy, or direct visualization at the time of repair. In this context, it is important to notice that the registration of an injury might be influenced by the method of data collection (17,30). Crossman et al. (12), for instance, demonstrated that athletes underestimated and coaches overestimated the disruption and short-term effects of an injury when compared with medical professionals. Because bias resulting from data collection may lead to biased interpretation of the treatment effect, future studies should gather detailed data on physician consults and diagnostic procedures to allow appraisal of potential bias in estimating treatment effects.

In conclusion, there is evidence that balance training or multifaceted training programs might be effective in preventing lower limb injuries (especially those of the knee and ankle joint) among adolescent and young adult athletes during ball sports. Although it might be presumed that training sessions should be performed for at least 10 min, more than one time per week for at least 3 months, the substantial variability in training parameters deserves further attention. For example, the training frequency and duration of the programs ranged from one to seven sessions per week and between 3 and 12 months, respectively. Therefore, potential underlying dose–response relationships should be evaluated in more detail. In addition, the generalizability of the results to other high-risk sports and age groups remains unclear. Further research should also concentrate on physiological mechanisms of PT/NT to promote a more differentiated and mechanism-based application and to identify the most appropriate and effective training components for preventing injuries in specific sports and populations.

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