Neuromuscular training injury prevention strategies in youth sport: a systematic review and meta-analysis

Carolyn A Emery,1,2 Thierry-Olivier Roy,3 Jackie L Whittaker,1,2 Alberto Nettel-Aguirre,1,2 Willem van Mechelen4

ABSTRACT
Youth have very high participation and injury rates in sport. Sport is the leading cause of injury in youth. Sport injury reduces future participation in physical activity which adversely affects future health. Sport injury may lead to overweight/obesity and post-traumatic osteoarthritis. The objective of the systematic review and meta-analysis was to evaluate the efficacy of injury prevention neuromuscular training strategies in youth sport. Three electronic databases were systematically searched up to September 2014. Studies selected met the following criteria: original data; analytic prospective design; investigated a neuromuscular training prevention strategy intervention(s) and included outcomes for injury sustained during sport participation. Two authors assessed the quality of evidence using Downs and Black (DB) criteria. Meta-analyses including randomised controlled trials only (RCTs) to ensure study design homogeneity were completed for lower extremity and knee injury outcomes. Of 2504 potentially relevant studies, 25 were included. Meta-analysis revealed a combined preventative effect of neuromuscular training in reducing the risk of lower extremity injury (incidence rate ratio: IRR=0.64 (95% CI 0.49 to 0.84)). Though not statistically significant, the point estimate suggests a protective effect of such programmes in reducing the risk of knee injury (IRR=0.74 (95% CI 0.51 to 1.07)). There is evidence for the effectiveness of neuromuscular training strategies in the reduction of injury in numerous team sports. Lack of uptake and ongoing maintenance of such programmes is an ongoing concern. A focus on implementation is critical to influence knowledge, behaviour change and sustainability of evidence informed injury prevention practice.

BACKGROUND
Youth have very high sport participation rates and sport participation has important health implications for our young population including the psychosocial benefits of greater self-esteem, motor skill development, socialisation, teamwork, competition and stress reduction. However, sport is also the leading cause of injury in adolescents, accounting for >30% of injuries in this population across many countries.1–4 The estimated injury incidence proportion in youth sport is 35 injuries/100 youth annually requiring medical attention (ages 11–18).1–6 Lower extremity injuries are among the most common, accounting for over 60% of the overall injury burden in youth sport.1–6 Sport injury may also lead to decreased sport participation and associated all-cause morbidity, overweight/obesity and post-traumatic osteoarthritis.7–8 As such, reducing the public health burden associated with injury in youth sport is critical. The combination of high sport-specific participation and high-injury rates leads to the highest burden of injury in youth sport. The highest rates of injury and overall injury burden for boys and girls are reported in team sports.5–6 For boys, the highest injury rates in team sport are reported in ice hockey, rugby, basketball, soccer, wrestling, running and football. For girls, the highest sport-specific injury rates in team sports are reported in basketball, soccer, ice hockey, European handball, running and field hockey.7–10 Reduction of sport injury where the public health burden is the greatest would have a major impact on quality of life through the promotion of physical activity.

The model of choice in the evaluation of injury prevention strategies in youth sport over the past two decades continues to be the van Mechelen four-stage model developed in 1992.11 The model establishes the need to first identify the extent of injury through injury surveillance followed by identifying risk factors for injury in the population of interest. Third, injury prevention strategies require development and validation prior to evaluation studies that measure the impact of the prevention strategy using appropriate surveillance. A randomised controlled trial (RCT) is the ideal research design to evaluate the efficacy of a prevention strategy; however, when an RCT is not plausible, a quasi-experimental or observational cohort study is often used.12 Further to the van Mechelen model,11 the TRIPP framework describes two additional steps that are required to translate evidence of effectiveness to practice.13 The additional steps include a description of the intervention context to inform implementation strategies and evaluation of the effectiveness of preventive measures in the implementation context.13

It is impossible to eliminate all injury in youth sport; however, injury prevention strategies can reduce the number and seriousness of injuries. Based on relative burden, the focus of much of the evidence surrounding injury prevention in youth sport has been on reducing the risk of lower extremity injuries. Until the past decade, there has been a relative paucity of rigorous scientific evaluation examining the efficacy of injury prevention strategies in youth sport.14 Historically, epidemiological research focused on the evaluation of prevention strategies in elite adult athlete (amateur and professional) populations where injury surveillance...
practice was more commonly established with the presence of medical staff within the sport structure.¹⁴ As a result, previous recommendations for injury prevention practice in youth sport have relied heavily on studies in adult elite sport populations.⁹ ¹⁵–¹⁷ In team and school settings, injury prevention strategies have most frequently focused on team or class-based neuromuscular training strategies to address the burden of lower extremity injuries.⁹ ¹⁵–¹⁷ These neuromuscular training strategies primarily target intrinsic risk factors (eg, previous injury, decreased strength, endurance, flexibility and balance).

The objectives of this systematic review and meta-analysis were to evaluate the efficacy of injury prevention neuromuscular training strategies in youth sport, to estimate a summary combined effect of such strategies based on RCT evidence only and to make recommendations for best practice and future research in injury prevention in youth team sports.

**METHODS**

**Data sources and search strategy**

Relevant studies were identified through an internet-based search of three databases (PubMed, EMBASE and Ovid/MEDLINE) from their inception up to 18 September 2014. Only articles published primarily in English and second in French and published in peer-reviewed journals were tracked. A combination of medical subject headings (MeSH) and text words was used to execute each search. Search terms were split into three groups and each of them contained three terms: Injury type: athletic injuries (MeSH), sport injury (tw), injury (tw); Population description: child (MeSH & tw), youth (MeSH & tw), team sport (MeSH & tw); Intervention description: injury prevention (MeSH & tw), intervention (tw), warm-up (tw). There were 11 possibilities of combinations for obtaining results from each database. Moreover, a hand search of references from identified studies was used to identify relevant studies not identified in the search strategies.

**Selection of studies**

The titles and corresponding abstracts of returned records from each search strategy that identified less than 300 records, after accounting for duplication, were reviewed to identify potentially relevant studies (TOR). The full text of all potentially relevant studies was then independently reviewed to determine final study selection (TOR, CAE). Study inclusion criteria were: (1) Contained original data (full-text paper published); (2) Investigated an outcome of sport injury including youth sport; (3) Evaluated an injury prevention intervention including neuromuscular training components (eg, balance, agility, strength, neuromuscular control); (4) Included sport participants 19 years of age or younger; (5) Analytical study design (including RCT, quasi-experimental or cohort study); (6) Peer-reviewed. Exclusion criteria were: (1) Study population was not exclusively youth sport participants under age 19 or did not evaluate intervention efficacy in a subpopulation that was under age 19; (2) Full text manuscript unavailable.

**Data extraction and quality assessment**

Data extracted from each study included: authors, study design, study duration, country, participants (sport, level, sex, age and sample size for intervention and control groups), injury definition, intervention and control description, incidence rate or incidence proportion reported for each of the intervention and control groups and effect estimate (incidence rate ratio, risk ratio or OR).

Two authors (TOR and/or CAE and/or JLW) independently assessed the quality of evidence of each study based on the Downs and Black (DB) quality assessment tool.¹⁸ This tool uses 27 criteria (maximum score 33 points) to assess study reporting, external validity, internal validity (eg, bias and confounding) and power. Discrepancies in DB scoring were resolved by consensus between the two authors who rated the study and, if required, a third author was consulted to obtain consensus.

**Meta-analyses**

Meta-analyses were conducted based on available outcomes of RCTs only, ensuring study design homogeneity and minimising the effect of selection bias in non-randomised study designs. Combined estimates of effect measure were produced using incidence rate ratios (IRR) based on a random effects model for studies examining overall lower extremity injury outcome and knee injury outcomes in youth sport.

**RESULTS**

The initial search yielded 2504 studies (including 37 identified through a reference list search; figure 1). After removal of duplicates and studies not meeting inclusion criteria based on title and abstract review, this was narrowed to 196 (TOR). Subsequent to further manuscript evaluation by two independent reviewers (TOR and CAE), 171 were excluded. In total, 25 studies were identified and categorised by sport (table 1 and online supplementary table S2).¹⁹–⁴³ Fifteen studies are RCTs with the remaining 10 being quasi-experimental (non-randomised experimental design) and cohort studies.⁹–¹⁷ The sports included are youth soccer (11), European handball (3), American football (2), basketball (2), Australian rules football (1), multisport (4) and school-based (2). In total, 13 studies included female youth sport participants only, 5 included male sport participants only and 7 included both. A diversity of at-risk sport-specific and school-based youth sport populations has been targeted for injury prevention neuromuscular training strategy evaluations.

In youth sport participant populations, multifaceted neuromuscular training programmes (eg, balance, strength, agility) implemented as preseason and/or warm-up training strategies have been shown to reduce the incidence of injury in sports such as soccer, European handball, American football, basketball, Australian rules football and multisport between 28% and 80%.¹⁹–⁴⁰ ⁴³ With few exceptions that demonstrate no preventative effect in youth sport.²⁷ ⁴¹ ⁴² ⁴³ In addition, the evidence suggests the efficacy of such neuromuscular training programmes in the reduction of knee injuries by 45–83%²⁰ ²³ ²⁵ ²⁶ ²⁹ ³⁰ and a significant trend supporting efficacy in the reduction of ankle injuries by 44–86%.³⁰ ³³ The median methodological quality for all 25 studies, based on the DB criteria, was 20/33 (range 8–26), whereas for the 9 RCT studies included in the meta-analyses which included lower extremity and/or knee injury outcome, based on the DB criteria, it was 23/33 (range 18–26). The aim of the DB criteria is to assess the methodological quality of randomised and non-randomised intervention studies. Areas in which studies were frequently limited included: lacked reporting of adverse events, incomplete description of how the participating sample was representative of the population of interest, limited description of the characteristics of those lost to follow-up, inadequate sample size or lacked reporting of a priori sample size and lack of adjustment for potential confounding.

Meta-analyses conducted based on available outcomes of RCTs to produce combined estimates of measure of effect using...
incidence rate ratios (IRR) for eight studies examining overall lower extremity injury outcome and five studies examining knee injury outcomes specifically in youth sport are demonstrated in figures 1 and 2, respectively. The size of the box in these figures represents the relative weights given to each study in calculating the overall summary measure. The weights depend on the SEs of the IRR. The combined estimate for RCT studies examining a preventative effect of neuromuscular training in the reduction of lower extremity injuries in youth team sport (soccer, European handball, basketball) demonstrates a significant overall protective effect (IRR=0.64 (95% CI 0.49 to 0.84) or a 36% reduction in lower extremity injury risk; figure 1). The combined estimate for RCT studies examining the preventative effect of neuromuscular training in the reduction of knee injuries in youth team sport (soccer, European handball, basketball) suggests a protective effect of knee injuries specifically, but this finding is not statistically significant (IRR=0.74 (95% CI 0.51 to 1.07) or a 26% reduction in knee injury risk; figures 2 and 3).

**DISCUSSION**

A rigorous systematic review and meta-analyses based on available RCTs has demonstrated a substantial overall protective effect of neuromuscular injury prevention training programmes in youth team sport for the reduction of lower extremity injuries (IRR 0.64, 95% CI 0.49 to 0.84) and suggests a potential

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**Table 1** Search strategy and results of the systematic literature search, with total number of unique articles per database

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*Cell values represent: # potentially relevant articles/# articles included in systematic review.
1=Athletic injuries [MeSH], 2=Children [MeSH/tw], 3=Injury Prevention [tw], 4=Sport Injury [tw], 5=Youth [tw], 6=Team sport [tw], 7=Interventions. 8=Injury [tw], 9=Warm-up [tw].
MeSH, Medical subject heading, tw, text word.
reduction for knee injuries (IRR 0.74, 95% CI 0.51 to 1.07). The findings of this systematic review extend those of previous reviews in youth sport by the addition of rigorous RCTs published in the past decade. In addition, the meta-analyses contribute specifically to the adolescent injury prevention evaluation literature. The consistency of high-quality RCT evidence in youth team sport supports implementing practice recommendations related to neuromuscular training programmes for injury prevention in youth team sports including soccer, European handball, US football and basketball.

A consistency of the findings was that the majority of these neuromuscular training strategies included components of balance, agility and strength. In this systematic review, only three studies failed to demonstrate any protective effect of neuromuscular training in youth sport. Steffen et al. reported that low compliance to the warm-up programme may have influenced the lack of protective effect of such a programme. Pfeiffer et al. evaluated a programme that was primarily focused on jump training, did not include a balance training component and failed to demonstrate a protective effect in reducing the risk of anterior cruciate ligament injury specifically. Collard et al. evaluated a school-based programme in younger children (ages 10–12) which included only 5 min of exercises (strength, speed, agility and coordination) but did not include a balance training component.

Which components of neuromuscular training have the most effect?

As the majority of studies in youth examining neuromuscular training strategies include multiple components (e.g., strength, balance, agility), it is difficult to assess the contribution of each component. Two recent systematic reviews that include a combination of adult and youth athlete studies have attempted to elucidate this issue. On the basis of meta-analyses including RCT studies only, Lauersen et al. demonstrated preventive benefits of neuromuscular training intervention programmes focused on components including strength and proprioception/balance, but no preventative effect associated with programmes focused on stretching across numerous sports. In addition, multifaceted programmes demonstrated the greatest overall protective effect, consistent with the youth studies included in this review.

Consistent with these findings, Herman et al. found a protective effect across multifaceted neuromuscular training strategies in multiple sports with meta-analyses supporting the efficacy of such programmes in reducing the risk of lower extremity injury and knee injuries and demonstrated a trend towards a protective effect in reducing the risk of hip and thigh and ankle sprain injuries. Further, Rossler et al. combined data from RCT and non-randomised study designs (cohort and quasi-experimental) in youth sport and report a protective effect of exercise interventions in reducing the risk of overall lower extremity injury (RR=0.57 (95% CI 0.44 to 0.72)), knee injury (RR=0.32 (95% CI 0.15 to 0.68)) and ankle injury (RR=0.51 (95% CI 0.31 to 0.81)). Further, they demonstrated a greater protective effect when programmes included jumping and/or plyometric training (RR=0.45 (95% CI 0.35 to 0.57)) compared to those without (RR=0.74 (95% CI 0.61 to 0.90), p=0.003)). Previous meta-analyses including neuromuscular training interventions in soccer, however, have demonstrated that selection bias inherent in non-randomised study designs may lead to an overestimation of the protective effect of such programmes.

As such, the results from non-randomised studies should be interpreted with caution and perhaps not combined with RCT data to estimated combined effect.

Figure 2  Forest plot based on meta-analysis evaluating lower extremity injury outcome.
estimates. Considering the evidence, there is consistency across the literature to support the preventative effect of multifaceted neuromuscular training programmes inclusive of strength, balance and agility components in reducing the risk of lower extremity injuries in youth sport.

Limitations
As the conclusions and recommendations contained within this review are based on a synthesis and evaluation of existing literature, they are limited by the methodological weaknesses of the individual studies. Despite the strength of 15 of 25 studies (60%) being RCTs, 50% of all studies scoring >20/33 on Downs and Black assessment criteria, and a median score of 23 for RCT studies included in the meta-analyses, there are limitations to this systematic review. In five studies, exposure to risk was not considered and as such incidence rates could not be reported and effect estimates were based on incidence proportions alone. All studies included in the meta-analyses, however, considered exposure to risk.

The most significant threats to internal validity were associated with the lack of control for potential confounding factors (e.g., previous injury, age, sex). Selection bias was a concern in non-randomised designs. As such, it was deemed inappropriate to combine the results of randomised and non-randomised studies in the meta-analyses. The reporting of losses to follow-up were infrequent across studies and the characteristics of those lost to follow-up were rarely reported, making it difficult to determine if those lost to follow-up were systematically different from those who were not. The generalisability to the larger youth sport participant population is reasonable given the consistency of findings across multiple sports. The meta-analyses included RCTs in male and female youth soccer, basketball and European handball. While all sports involve running, jumping, landing and cutting with similar injury types and mechanisms of injury reported, it is possible that there was some heterogeneity of results by sport and/or sex that was not evaluated based on the limited number of sex-specific and sport-specific RCTs available. However, given the minimal attention in included studies to younger (<12 years) and non-competitive sport participants, the generalisability to a paediatric and non-elite sport population is more limited and requires further study.

Implications for best practice
Arguably, there is currently adequate evidence to inform practice and policy recommendations to prevent injuries in many youth sporting venues including soccer, European handball, US football and basketball. In addition, there is evidence from youth elite team sport participants to support the further development and evaluation of additional sport-specific and more global multifaceted injury prevention training strategies to reduce sport injuries in youth through appropriate RCT design in populations that have not been previously examined where lower extremity injury risk is high (e.g., rugby, field hockey, lacrosse, volleyball, school physical education). This will require implementation of valid injury surveillance prior to RCT evaluation.

While there is an increasing body of rigorous scientific evidence (including RCT evidence) to inform best practice in injury prevention in youth sport, there is evidence to support the lack of programme uptake and ongoing maintenance following an evaluation study. This highlights the need to focus on the implementation context and real-world effectiveness in evaluating prevention strategies in youth sport. In team sports such as European handball, it is evident that these programmes need to be sport-specific with a focus on coach training to ensure programme effectiveness. In soccer, lessons learnt from worldwide implementation of the FIFA 11+ also highlight the
importance of the coach in successful implementation.49 This is supported by research evaluating the implementation strategy for delivery of a team-based neuromuscular training warm-up programme, which highlights greater adherence when a comprehensive coach workshop precedes the coach-delivered intervention in a team-based setting in youth soccer.28 It may also be important to focus on player performance improvement as a side effect to injury prevention strategies in youth sport to facilitate uptake by coaches and players.50 Internationally, there is a deficiency in coach, player and parent knowledge and behaviours regarding injury prevention programmes in youth sport populations despite the evidence to support their implementation in soccer, European handball and football.33-48 A focus on the ongoing and sustainable implementation of effective injury prevention strategies in youth sport (eg, soccer, European handball, basketball, Australian rules football), in addition to further evaluation in sports where there is a paucity of research evaluating such programmes (eg, rugby, field hockey, volleyball, lacrosse, school physical education).

A focus on implementation is critical to shift knowledge, behaviour change and sustainability of evidence informed injury prevention practice.59 An argument has been made for a hierarchy of responsibility with the lowest level of responsibility assigned to the child and the highest level to those organisations or groups with the potential to effect the most change.48 The justification for this approach is based on the limited evidence for the effectiveness of strategies relying solely on behaviour change in children and parents and the level of perceptual and cognitive development in children that inadequately prepares them to take primary responsibility for their own safety in sport.54 In addition, a greater focus on implementation research is key, including behaviour change in the youth sport population and the critical role of coach behaviour related to injury prevention.44 A focus on implementation is critical to influence knowledge, behaviour change and sustainability of evidence informed injury prevention practice and policy.

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