Current state of concussion prevention strategies: a systematic review and meta-analysis of prospective, controlled studies

Daniel K Schneider,1,2 Ravi K Grandhi,2,3 Purnima Bansal,4 George E Kuntz IV,2 Kate E Webster,5 Kelsey Logan,1 Kim D Barber Foss,1,6 Gregory D Myer1,2,3,7,8,9

ABSTRACT
Objective The aim of the current review was to systematically identify, evaluate and synthesise trials that examine concussion prevention via equipment, educational programmes and training programmes.

Data sources PubMed and EBSCO host (CINAHL, MEDLINE, SPORTDiscus).

Eligibility criteria for selecting studies The electronic databases PubMed and EBSCO were searched using the phrases: concussion prevention equipment, concussion prevention training and concussion prevention education. Included studies utilised a prospective study design to evaluate the preventative effect of: (1) equipment, (2) training or (3) educational programmes on the incidence of concussions in comparison to a control group.

Data extraction Demographic data and intervention methods were recorded. Intervention and control group concussion rates and superficial head injury rates were extracted and combined using random-effects relative risk meta-analysis.

Results 14 studies evaluated interventions of novel protective equipment. One prospective investigation evaluated an educational programme. The relative risk of concussion for participants wearing interventional protective equipment, training programmes or educational programmes was calculated.

Conclusions Prospective controlled studies indicate that certain protective equipment may prevent superficial head injury, but these items are suboptimal for concussion prevention in sport.

INTRODUCTION
Each year, at least 1.6–3.8 million sports-related and recreation-related mild traumatic brain injuries (TBIs) occur in the USA.1 Youth ages of 10–14 and 15–19 years are the most affected.2 Symptoms of concussion are often non-specific and include headache, cognitive slowing, emotional lability/irritability, amnesia, difficulty concentrating, loss of consciousness, nausea/vomiting, and/or sleep disturbances.3 If an impact to the head or body results in any concussion symptoms, the individual should be removed from the activity for observation and diagnostic evaluation. The under-reporting of concussion injury by athletes due to fear of time lost from participation is an area of great concern.4–6 The majority of individuals return to their baseline levels of cognition within 1–3 weeks after a concussion injury.7 Recovery falls outside of this expected time period in 10–15% of individuals, which is referred to as post concussion syndrome.8 Post concussion syndrome causes problems with academic and work function, as well as activities of daily living. There is controversy on whether more severe manifestations such as second impact syndrome (severe neurological injury from swelling of the brain after second impact following an initial insult without complete recovery) and chronic traumatic encephalopathy (permanent changes in mood, behaviour and cognition) result from concussion.9 While this discussion falls outside the scope of this paper, there are no established treatments for these serious, life-altering syndromes that highlight the importance of protecting the brain early in life. The concern about potential long-term problems from concussion is recognised by medical and lay populations. As a result, there have been escalating demands for research in methods for preventing concussion.8

Many methods have been proposed to prevent concussions, including (1) education (Centers for Disease Control Heads Up Football campaign)9 and legislation by rule changes; (2) use of personal equipment (helmets, headgear, mouth guards, face shields, etc) to decrease impact forces on the head and (3) by collision anticipation for changing body postures to tackle and absorb impact better.10–11 While these multimodal management changes may have led to increased injury reporting by athletes, this alone is unlikely to explain the vastly increased rates of TBI-related emergency department and hospitalisation visits,70% and 11%, respectively, from 2001 to 2010.12 In addition, the concussion prevention effects of rugby headgear continue to be debated while many believe that these items have more efficacy in preventing superficial head injuries.13 The primary aim of this systematic review and meta-analysis was to evaluate the efficacy of interventional protective equipment, training programmes and education in regard to concussion prevention. A secondary aim was to evaluate the...
efficacy of headgear and face shields in preventing superficial head injuries as reported in the included studies.

**METHODS**

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed when conducting and reporting this review.

**Literature search**

A systematic review of the current literature was performed using the electronic databases PubMed (1969 to 17 December 2013) and EBSCO host (CINAHL, MEDLINE, SPORTDiscus; 2002 to 17 December 2015). The following phrases were utilised as keywords in the search: concussion prevention equipment, concussion prevention training and concussion prevention education, and results were further limited to articles written in English (table 1).

In addition to the electronic search, experts in the field were contacted for further study suggestions, and references from review papers were examined to identify any further relevant articles for potential inclusion. Publication details from all studies identified in the literature search were exported to bibliographic software.

The electronic literature search yielded abstracts for initial review, which were loaded into an electronic reference database (EndNote X7, Thompson Reuters). The ‘find duplicates’ function was utilised for initial duplicate removal. The remaining articles were alphabetised by lead author and hand searched to remove any further duplicates. Full-text versions were downloaded if the title or abstract discussed concussion preventative equipment, training or education. Full-text articles were reviewed by one author (DKS) and included or excluded based on the criteria described in box 1. Articles were limited to sport and recreation. References from the included articles were also reviewed to ensure no article had been overlooked.

**Risk of bias and level of evidence**

The Physiotherapy Evidence Database (PEDro) scale was used to assess risk of bias of the included studies. Each study was assessed independently by two authors, and any disagreements were resolved by arbitration and consensus discussion among the two reviewers (DKS and RKG). If a firm agreement was not reached, a third author (GDM) was consulted and provided the deciding vote. The Centre for Evidence-based Medicine Levels of Evidence (March 2009) assesses research design quality. The results of these assessments are shown in table 2.

**Data extraction and synthesis**

One author extracted data from the included studies (DKS). The study design, population and intervention method were recorded for each study. Population size, number of participants in each study arm and mean/median age data were also extracted. Interventional protective equipment was defined as equipment worn by athletes during practice or game settings that was beyond the current standard-issued equipment normally utilised in the given sport.

**Concussion rates**

The number of concussions in the total population and intervention and control groups was recorded, as were crude injury rates, exposure data and incidence rates (where applicable). Thompson et al. defined ‘brain injury’ as a concussion or more serious intracranial injury. As these results were not specific to concussions, this study was excluded from the relative risk meta-analysis for concussions. The specific nature of the exposure data was noted (ie, player hours, player game hours, player exposures). Crude injury and incidence rates were calculated from available data if they were not directly reported by investigators. Incidence rate ratios were calculated by dividing the interventional incidence rate by the control incidence rate. Adjusted incidence rate ratios were not utilised in this study. Those studies which reported population sizes and the number of concussions in groups with and without interventions were combined using a random-effects relative risk meta-analysis (weighted for individual study size) using StatsDirect software (Altrincham, UK). The relative risk statistic compares the number of cumulative incidences of concussion in the interventional groups versus the cumulative incidences of concussion in the standard practice/control groups. A relative risk <1 correlates with a decreased risk of concussion in the interventional group compared with the control group. The results from eight studies evaluating interventions aimed at concussion incidence reduction were combined, and a pooled estimate was presented in a forest plot. In addition, the results from seven studies evaluating interventional protective equipment were combined, and a pooled estimate is presented in a forest plot. Heterogeneity was assessed using the I² statistic.

**Superficial head injury**

Studies that reported population sizes and the number of head injuries, including superficial injuries (lacerations, abrasions, etc.) were recorded in a forest plot. The number of superficial injuries for the intervention and control groups was combined using a random-effects relative risk meta-analysis (weighted for individual study size) using StatsDirect software (Altrincham, UK). The relative risk statistic compares the number of cumulative superficial injuries in the interventional groups versus the cumulative superficial injuries in the standard practice/control groups. A relative risk <1 correlates with a decreased risk of superficial injury in the interventional group compared with the control group. The results from three studies evaluating interventions aimed at superficial head injury incidence reduction were combined, and a pooled estimate was presented in a forest plot. Heterogeneity was assessed using the I² statistic.

**Table 1** Electronic database search results

<table>
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<tr>
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<td>‘Concussion prevention education’</td>
<td>158</td>
<td>19</td>
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</tbody>
</table>

The number of citations found for each search term in both databases are shown above.
Concussions, in groups with and without interventional protective equipment were also analysed using random-effects relative risk meta-analysis. McIntosh et al reported ‘concussions’ as a subset of ‘head injuries’. As such, the reported number of concussions was subtracted from the number of head injuries to calculate superficial head injuries. The results from three individual studies were combined.14 16 20 and a pooled estimate is presented in a forest plot. Heterogeneity was assessed using the I² statistic.

RESULTS

Search results

The electronic literature search yielded 573 abstracts for initial review, with 344 articles remaining after duplicate removal. Of the 344 abstracts, 47 full-text articles were reviewed. A further 21 articles were identified from references and reviewed. One article was identified during the revision process and included. References from the included articles were also reviewed to ensure no article had been overlooked; however, this did not result in the inclusion of any previously unidentified articles. At the conclusion of the search, 15 articles met the inclusion criteria and were included in the present study (figure 1). An outline of the literature review process can be seen in figure 2.

The mean PEDro score was 3.5 (range=2–6). The scores on the PEDro scale were low relative to the maximum possible total score of 10 due to the non-randomised nature of 10 out of 15 included studies.

Of the 15 included studies, seven evaluated helmets/headgear,14 16 17 20 22–25 8 evaluated mouthguards,14 15 19 21–24 26 27 two evaluated hockey face shields16 28 and one evaluated an American football tackling technique educational programme.18 No prospective studies were identified that evaluated training protocols. Six studies evaluated concussion incidence in rugby,15 20 22–25 six evaluated American football,15 19–19 21–27 seven evaluated cycling,16 28 one evaluated basketball26 and one evaluated bicycling.14 Three of 15 included studies evaluated both male and female participants.14 15 24 The age of participants evaluated in the included study ranged from 5-year-old football players to bicyclists >40 years old.14 18 One study evaluated rugby players in an under-15-year-old league,24 and the remaining 12 studies evaluated high school aged athletes (<16 years old) and university/young professional athletes (<21 years old). The data extracted from each study are presented in table 3.

Seven of the included studies did not report data needed to be included in meta-analysis calculations.22–28 None of these seven studies found a significant difference in concussion incidence between participants who wore or who did not wear interventional protective equipment in non-adjusted comparisons. The relative risk of concussion for participants wearing interventional protective equipment compared with those that wore standard or no protective equipment was (RR=0.82, 95% CI 0.56 to 1.20, $\chi^2=1.06$, p=0.30; $I^2=86.7$%, 95% CI 73.3% to 91.8%; figure 3). When including the lone study that evaluated an educational programme, the relative risk of concussion for participants in the intervention study arms of eight studies was not significantly different than participants in the control arms of those studies (RR=0.78, 95% CI 0.55 to 1.11, $\chi^2=1.8$, p=0.17; $I^2=85.3$%, 95% CI 71.5% to 90.8%; figure 4). The relative risk of superficial head injury was more than halved in participants that wore interventional protective equipment relative to their counterparts (RR=0.41, 95% CI 0.31 to 0.56, $\chi^2=34.13$, p<0.0001; $I^2=53.1$%, 95% CI 0% to 85.2%; figure 5).

DISCUSSION

This systematic review and meta-analysis evaluated the efficacy of existing methods of concussion prevention that have been studied prospectively. The findings characterise the efficacy of concussion preventative equipment and highlight a lack of prospective randomised controlled trials designed to determine the efficacy of these and other methods of concussion prevention. Concussions lead to an estimated 2.5 million hospital admissions, emergency room visits or deaths in the USA annually.12 There are countless more incidents of mild trauma that do not appear in hospitals.15 Protective equipment, including headgear,

Table 2: Levels of evidence and the Physiotherapy Evidence Database (PEDro) scores for all included studies

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The PEDro scale is optimal for evaluating randomised controlled trials; therefore, it should be interpreted with caution in the studies included here as many are non-randomised. (1) Eligibility criteria specified; (2) random allocation of participants; (3) allocation concealed; (4) similar groups at baseline; (5) blinding of participants; (6) blinding of intervention providers; (7) blinding of outcome assessors; (8) outcomes obtained from 85% of participants; (9) use of intent-to-treat analysis if protocol violated; (10) between-group statistical comparison; (11) point measures and measures of variability. A ‘1’ indicates a ‘yes’ score and a ‘–’ indicates a ‘no’ score. Note that item (1) is not utilised in calculating the total PEDro score.
helmets, mouthguards and face shields, may play roles in reducing the incidence of concussion, but evidence from existing prospective studies indicates that the preventative effects of these items as a group may be limited, as depicted by the pooled relative risk of 0.82 (figure 3). Athletes wearing interventional equipment including rugby headgear, full ice hockey face shields and bicycle helmets had a relative superficial head injury risk of 0.41 compared with those wearing standard or no equipment (figure 5). The discrepancy between the two relative risk calculations in figures 3 and 5 illustrates that existing protective equipment designed to be worn on the head during sports participation is successful in prevention of superficial injuries, but suboptimal in terms of concussion prevention. While the risk of concussion was still not significantly different between intervention and control groups when including one study that evaluated an American football tackling technique educational programme,18 risk was reduced to a greater extent (RR=0.78; figure 4), indicating that concussion prevention may benefit from a multidisciplinary approach.

**Headgear and helmets**
Rugby is the most popular team collision sport internationally; however, players are unprotected from impact forces relative to...
<table>
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<tr>
<th>Paper</th>
<th>Year</th>
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<th>Type of exposures</th>
<th>INT group</th>
<th>INT population size</th>
<th>INT concussions</th>
<th>INT crude concussion rate</th>
<th>CTRL group</th>
<th>CTRL population size</th>
<th>CTRL concussions</th>
<th>CTRL crude concussion rate</th>
<th>Concussion incidence per 1000 exposures</th>
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<td>Bicycling</td>
<td>N</td>
<td>N</td>
<td>NR</td>
<td>Helmet</td>
<td>1718</td>
<td>62</td>
<td>0.04</td>
<td>NR</td>
<td>1672</td>
<td>141</td>
<td>0.08</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Winters and DeMont</td>
<td>2014</td>
<td>American Football</td>
<td>Y</td>
<td>N</td>
<td>NR</td>
<td>Custom MG</td>
<td>220</td>
<td>8</td>
<td>0.04</td>
<td>NR</td>
<td>192</td>
<td>16</td>
<td>0.08</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Wisniewski et al</td>
<td>2004</td>
<td>American Football</td>
<td>N</td>
<td>Y</td>
<td>Practices/games</td>
<td>Custom MG</td>
<td>169</td>
<td>NR</td>
<td>0.99</td>
<td>Standard MG</td>
<td>NR</td>
<td>200</td>
<td>1.10</td>
<td>0.9</td>
<td></td>
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*Total population size=304; concussions=22.

CTRL, control; HG, headgear; HUF, Heads Up Football; PW, Pop Warner; INT, interventional; MG, mouthguard; N, no; NR, not reported; Y, yes.
other collision sports (eg, ice hockey, football).\textsuperscript{22, 23} Approximately 25% of injuries sustained during rugby are head injuries, with about 10% of injuries being concussions,\textsuperscript{20, 22, 29, 30} which occur at rates between 0.62 and 9.1/1000 player game hours.\textsuperscript{31, 32} These high rates have led investigators to examine the effects of protective headgear on concussion incidence in this population. Headgear sanctioned for use in rugby is made of soft polyethylene foam but lacks a hard shell to surround this padding as seen in helmets utilised in other sports.\textsuperscript{20, 33} Existing evidence indicates that this headgear may have a limited impact on reducing concussion incidence during rugby.\textsuperscript{11} The mean incidence rate ratio for the four studies that reported concussion incidence rates in athletes who wore headgear during games and in those who did not was 0.9. Three of these studies reported no differences in concussion incidence between those who wore headgear and those who did not.\textsuperscript{20, 22, 25} As laboratory tests and previous prospective studies had indicated that ‘standard’ headgear may be unable to attenuate impact and reduce head acceleration,\textsuperscript{24, 25, 34} in examination of ‘modified headgear’ (made with 16 mm thick, 60 kg/m\textsuperscript{3} polyethylene foam vs 10 mm thick, 45 kg/m\textsuperscript{3} polyethylene foam in standard headgear), similar concussion incidence was noted in those who wore the new equipment and those who did not wear any headgear.\textsuperscript{20} Conversely, other investigations have reported decreased concussion incidence rates among those wearing headgear compared with those who did not.\textsuperscript{22, 23}

These findings are complicated by risk compensation, a strategy involving increasingly reckless play by those wearing protective equipment.\textsuperscript{35} A study of <16-year-old male rugby players reported that players believe they can tackle harder and more confidently while wearing headgear.\textsuperscript{36} This behaviour modification may negate some or all of the potential concussion-preventing benefits provided by headgear. In addition, Hollis et al\textsuperscript{22} noted that ‘fewer risk takers wore headgear’
in their cohort. This potential bias towards more conservative play may have played a role in the reduced concussion incidence in those who wore headgear. Practice exposures were accounted for in only one study, and two studies reported adjusted rate ratios accounting for previous injury. The remaining three studies may have underestimated true concussion incidence by not considering these variables.

Although the evidence on headgear and concussion prevention remains unclear, headgear has been used within rugby with increasing frequency recently. This trend was preceded by a study reporting a reduced incidence of superficial head injuries such as abrasions and contusions in players who wore headgear. Results on this topic among the included studies are mixed, with Marshall et al reporting similar results but with McIntosh et al reporting no significant differences in superficial head injuries between those with headgear and those without. However, McIntosh et al did report a reduced number of superficial head injuries in those wearing standard headgear (figure 4) compared with players without headgear. Rugby participation has increased in the past decade, primarily without increased protective equipment relative to those who wore standard or no equipment.

Bicyclists wearing helmets also sustained fewer brain injuries (OR=0.33), defined by authors as ‘concussion’ and ‘more serious intracranial injury’, indicating that helmets were effective in preventing both superficial and intracranial injury. This protective effect was comparable in injuries stemming from both accidents with motor vehicles and other types of bike crashes, and the differences in protection afforded among three different styles of helmet were not significant. The evidence presented by these authors, however, is subject to certain confounding factors. As was the case with rugby players adjusting their playing style based on headgear use, some cyclists may feel that the protection afforded by helmets allows them to ride more aggressively. Conversely, certain cyclists wear helmets more often simply by nature of being more cautious riders.

Contact and collision sports, such as American football, are different from sports such as cycling by their very nature in that collisions involving the head are an expected component of normal play and thus the risk of concussions is greater. The front of the head is the most likely to be struck in a concussion-causing collision, although impacts to the side temporal area may also cause similar injuries. Helmets were not originally intended to prevent concussions; however, much attention has been given recently to improving the design of helmets for this purpose. Newer helmet designs have the potential to reduce concussion-causing impact forces, many of which occur at the crown of the helmet and at oblique angles on the helmet facemask. Collins et al found a decreased rate of concussions in examining high school football players who were equipped with the Riddell Revolution helmet relative to other standard helmets (p<0.027). One of the standard models, the Riddell VSR4, was recently compared with the Revolution model in a retrospective study, and those wearing the latter helmet had a 46.1% relative risk of concussion compared with their peers.

Although these studies show that better helmet technology reduced concussion occurrence in football players, since the time of their publishing these helmet models (and newer models with improved technology) have become the standard level of equipment, yet concussion rates remain high. In addition, a recent study of over 1300 high school football players, concussion risk did not change based on helmet age or brand/model. While helmets may continue to be effective in...
reducing the incidence of skull fracture and superficial head injuries, they do nothing to mitigate the effect of brain slosh (movement of the brain within the cranium allowing unfavourable energy absorption). Therefore, in terms of concussion prevention, football helmet improvements may be reaching a point of diminishing returns and are not likely to be the solution to the concussion issue we face today.

Mouthguards
Existing evidence on the relationship of mouthguards to concussion prevention has been inconclusive. Small sample sizes and a relative lack of studies highlight the need for quality research to characterise the effect (or lack thereof) of mouthguards. Regardless of current evidence, mouthguards have been touted as one potential concussion-prevention strategy for many years. Investigators theorise that mouthguards help dissipate the force absorbed by the mandible as the mandibular condyle approaches the glenoid fossa, and thick mouthguards can decrease the impact to the wearer’s head, reducing the potential for concussive injuries. Labella et al reported no difference in concussion incidence among basketball players with and without mouthguards. As mouthguards are best suited to protect from under-the-chin impacts to the mandible, their effect may be limited in basketball, as this type of hit is relatively uncommon in the sport.

Mouthguards generally come in three types: unmolded, traditional “boil-and-bite” and custom-fitted. Three of the included studies have examined the potential benefits of advanced and custom mouthguards over more common over-the-counter mouthguards. Barbic et al examined collegiate football and rugby players and found that those wearing a more advanced style of mouthguard (although not custom-fitted) were no less likely to sustain a concussion than those wearing a standard mouthguard of their choosing. Likewise, Wisniewski et al found no significant reduction in concussion injuries to college football players when comparing players with custom mouthguards to those wearing standard equipment. Two other included studies evaluated the relationship of concussion incidence and mouthguard use in rugby players and reported no reduction in TBIs in the groups wearing mouthguards, with one of the studies actually reporting increased incidence in mouthguard wearers. This increased incidence of concussion was also reported in high school football athletes wearing custom or specialised mouthguards. Conversely, it was found that custom-fitted mouthguards did significantly reduce concussion incidence in comparison to over-the-counter mouthguards in a cohort of high school football athletes, all of whom wore the same helmet. Such is the trend for the current body of evidence on the potential advantages of custom mouthguards: some studies find that there is significant risk reduction, while others conclude there is no difference between mouthguard types.

A number of confounding factors support the need for a more complete examination of the potential advantages of mouthguards. For example, in the study performed by Winters and DeMont, the custom-fit mouthguards that were found to significantly reduce concussions were thicker than over-the-counter mouthguards, suggesting that mouthguard thickness (rather than type) may be a more important element for reducing TBIs. Likewise, some studies did not account for athletic exposures, and the potential for under-reporting of injuries by team athletic trainers is a considerable limitation. Furthermore, the use of mouthguards in combination with helmets in sports such as football, where helmet use is already the norm, begs the question as to whether mouthguards (and consequently, mouthguard type) are even relevant for concussion prevention strategies. A need exists for closer and more rigorous examination of the mouthguard as a concussion prevention tool, with attention paid to mouthguard type and thickness and consideration given to the mechanism of injury in each sport studied.

Face shields
Ice hockey involves frequent high-impact collisions, which play a role in the high incidence of head and face injuries seen in the sport. Concussion is the most common head injury in ice hockey, with incidence ranging from 0.24 to 8.2 cases per 1000 exposures. Face shields gained popularity as a result of their efficacy at reducing the incidence of facial and eye injuries. However, these full face shields were implicated as a potential contributor to a trend of severe cervical spine injuries seen in the early late 1990s. Benson et al prospectively studied collegiate hockey players and found no difference in concussion incidence between players wearing full and half face shields and reported that those wearing full facial protection had a lower risk of facial lacerations and dental injuries and had less time lost from participation than those wearing half shields. A similar study was performed with elite-level amateur (junior A) players, as the governing bodies of these teams did not require full facial protection at the time due to persistent fears of spinal injuries. Conclusions from this investigation were comparable to those of the aforementioned study, supporting the notion that face shields decrease the incidence of face and eye injuries without increasing concussion risk. The National Collegiate Athletic Association now mandates full facial protection be worn by all players, while junior A players may sign a waiver at age 18 that enables them to wear a half shield. The International Ice Hockey Federation (IIHF), the governing body for the Olympics, mandates half shields for men and full shields for women. However, these organisations have not made these changes based on brain injury, as existing evidence suggests that face shields are not effective at preventing concussion.

Coach education programmes
While educational programmes focused on teaching safe techniques have gained popularity as a concussion prevention modality, only one prospective study evaluating such an intervention was identified. The Heads Up Football (HUF) programme stresses proper tackling technique, injury reduction strategies and awareness of pertinent issues in sports medicine. In addition, the Pop Warner (PW) youth football organisation has recently employed certain restrictions on contact between players as part their practice regulations. Kerr et al followed among youth football players (ages 5–13 years) for one season and compared the incidence rates of three groups: teams that implemented both the HUF programme and PW practice protocols, teams that used the HUF programme only, and teams that utilised neither. Investigators reported significantly lower total injury rates in the group which instituted both HUF and PW protocols. However, when considering concussions separately, only 11–15-year-old teams that instituted both HUF and PW protocols sustained concussions at a significantly lower rate than age-matched teams that did not use either protocol. These findings indicate that while technique training and practice time restrictions may be somewhat helpful in concussion prevention, the concussion prevention benefits these strategies afford may be limited to a specific subset of the at-risk athletic population.
Future directions
With current prospective evidence indicating that protective equipment may have limited impact in reducing concussions, it is necessary to evaluate other modalities to identify more optimal prevention strategies. During the literature search of this review, no prospective trials were identified that evaluated training protocols for concussion prevention. As head acceleration plays a role in the pathophysiology of concussions, prevention strategies involving the development of a strong and massive neck musculature have been proposed.62–64 In a study of high school soccer, basketball and lacrosse athletes, overall neck strength, a measure of combined strength in flexion, extension and lateral flexion, and neck circumference were lesser in athletes who sustained concussions in comparison to their uninjured peers.82 These qualities may be developed in relatively short periods of time with the implementation of a cervical resistance training programme. Isometric neck flexion and extension strength as well as neck girth can be increased significantly in just 8 weeks of training.84 Recently, investigators reported trends towards increased neck strength in rugby players after only 6 weeks of training.87 In addition, pilot results from an intervention that included a 5 min tackling drill without helmets and shoulder pads reduced head impacts in collegiate football players over a single competitive season.85 These findings indicate that prospective studies evaluating concussion incidence following the administration of preventative neck strength development and tackling technique programmes are warranted.

Vision training may also play a role in concussion prevention. Preseason vision enhancement training was implemented recently in collegiate football players using light boards, strobe glasses and tracking drills.86 Investigators compared concussion incidence during the 4 years in which training took place to the previous 4 years and found that trained players sustained fewer concussions and missed less time from participation. This study was limited by the lack of a control group and by differential participation levels in training by participants (not all participants underwent the same amount of training). This novel method calls for further analysis to help establish its potential to reduce concussions and to determine the optimal type and amount of visual training required to achieve the desired results.

Ongoing trials are currently investigating the role of cerebral venous engorgement and the role it may play in concussion prevention.88 By providing the brain with a tighter fit inside the cranium, this engorgement may minimise brain slosh, which may play a role in the aetiology of TBI.88–90 New research may be directed at clarifying these physiological mechanisms, as well as determining whether the hydrodynamics of 'head-butting' animals and their modification of jugular venous outflow can be mimicked in humans in an effort to mitigate slosh and reduce concussion incidence.91

Limitations
There are a number of limitations associated with the present review. A majority of the reviewed studies are not randomised controlled trials, which presents an obstacle to synthesising the highest level of evidence. As with many studies associated with the use of supplementary, external equipment, it is challenging to blind participants, evaluators and assessors. This may create inherent conflicts of interest during data collection and analysis. This lack of randomisation is reflected by the low mean PEDro score of 3.5. Moderate-to-high quality trials are characterised by a PEDro score of ≥6.92 Only one included study met this cut-off.13 The low methodological quality of the studies combined in the meta-analyses should be considered when interpreting the results of this report. The limitations of the utilised approach underscore the continued need for high-quality trials evaluating concussion prevention in the future.

In calculating relative risk for concussion, certain populations were combined in order to avoid including the same participants in the calculation more than once. McGuine et al19 evaluated high school football athletes who wore generic, custom or specialised mouthguards. The athletes who wore custom and specialised mouthguards were combined and compared with those who wore generic mouthguards. McIntosh et al50 evaluated the preventative effects of standard and modified headgear compared with no headgear in rugby athletes. These two populations were combined into a single headgear group and compared with athletes who did not wear headgear for this relative risk meta-analysis. Kerr et al18 compared the HUF programme in PW Football leagues and non-PW-affiliated leagues to leagues not using the HUF programme. The two interventional groups were combined in this review for comparison to the control group.

A corollary aim of this study was to evaluate the efficacy of headgear and face shields in preventing superficial head injuries in the included studies. We recognise that there is likely additional literature that examines the efficacy of these items in preventing superficial head injuries that were not included in this study due to the search criteria utilised to capture concussion prevention studies. As evaluating concussion prevention methods was the primary aim of this review, the current findings on superficial head injuries likely present an incomplete picture. Future research should aim to characterise the benefits of personal protective equipment in preventing both concussions and superficial head injuries.

The study by Collins et al17 is limited in that the interventional and standard helmets evaluated are both used only sparingly today. While we recognise the potential limitations of this investigation, we chose to include this study based on its fulfilment of the inclusion criteria for the current report. The fact that there are no other prospective trials that compare new, interventional helmets to older models is an illustration of the need for future research in this area. Another challenge is ensuring all concussions were identified and reported. Under-reporting of concussions has the potential to skew data, either in favour of or against the use of protective equipment. Objective diagnoses of concussions are often challenging and, as a result, many studies rely on self-reporting and the use of surveys. Many studies did not report the number of patients who wore or did not wear interventional equipment and/or the number of concussions sustained by those in each group, which prevented their inclusion in meta-analysis calculations. Furthermore, the included studies did not utilise clear standardised criteria and data collection methods, which create the potential for confounding factors to play a role in the evaluation of equipment.

Individuals included in the reviewed studies may have previously sustained subclinical concussions or experienced other head trauma, making them increasingly susceptible to repeat injury, which may occur despite the use of protective equipment. This previous incidence may lead such individuals to have an increased tendency to use cutting-edge protective equipment. In addition, those who wear protective equipment may have a tendency to perform more recklessly, increasingly their risk of concussions.35 36 49 These factors are not clearly highlighted in the studies and are beyond the scope of this review. Finally, there was considerable heterogeneity among the studies included in both concussion relative risk meta-analysis. The findings from the included studies are likely to be sport-specific.

as each sport entails a variety of unique concussion mechanisms. Without prior studies indicating potential benefits, concussion risk may not be adequately addressed simply by providing athletes with equipment that has been efficacious in other sports populations.

CONCLUSION
This systematic review and meta-analysis characterises the existing prospective evidence on protective equipment including helmets/headgear, mouthguards and face shields, as well as a prospective trial evaluating an educational programme for coaches. Concussions cause a significant healthcare burden and affect the long-term health of many young athletes worldwide. Existing prospective trials show no difference in the relative risk of concussion in athletes wearing novel protective equipment relative to athletes wearing standard equipment. Some of these items (headgear, full face shield, bicycle helmet) may prevent superficial head injury, as relative risk of these injuries in athletes wearing novel protective equipment was less than half of that of their counterparts. However, the effectiveness of protective equipment may be limited to specific settings such as bicycling, and newer models of equipment such as football helmets have yet to be studied prospectively. As concussion-related hospital visits continue to increase, it is necessary to evaluate novel methods for concussion prevention. Investigators should strive to perform prospective, randomised controlled trials focused on novel approaches to enhance the evidence regarding these new modalities and brain injury prevention strategies.

Twitter Follow Gregory Myer at @gregmyer11

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Current state of concussion prevention strategies: a systematic review and meta-analysis of prospective, controlled studies

Daniel K Schneider, Ravi K Grandhi, Purnima Bansal, George E Kuntz IV, Kate E Webster, Kelsey Logan, Kim D Barber Foss and Gregory D Myer

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