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

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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 enrolled in the interventional arms of trials was not significantly different from that in standard practice arms (RR=0.78, 95% CI 0.55 to 1.11, χ^2=1.8, p=0.17; I^2=85.3%, 95% CI 71.5% to 90.8%). The relative risk of concussion for participants wearing protective equipment (ie, headgear, full face shields) relative to their counterparts wearing standard or no equipment, calculated from seven available reports, showed no effect of intervention (RR=0.82, 95% CI 0.56 to 1.20, χ^2=1.06, p=0.30; I^2=86.7%, 95% CI 73.3% to 91.8%). The relative risk of superficial head injury for participants wearing protective equipment relative to their counterparts, calculated from three reports, showed a significant risk reduction (RR=0.41, 95% CI 0.31 to 0.56, χ^2=34.13, p<0.0001; I^2=53.1%, 95% CI 0% to 85.2%).
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 labiality/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 5] The majority of individuals return to their baseline levels of cognition within 1–3 weeks after a concussion injury.[3] Recovery falls outside of this expected time period in 10–15% of individuals, which is referred to as postconcussion syndrome.[6] Postconcussion 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.[7] 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 2015) 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 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. Study designs are categorised by the research question that they answer (therapy/prevention/harm, prognosis, diagnosis, differential diagnosis/symptom prevalence, or economic and decision analysis) and given a rating, or level, ranging from 1a (systematic reviews) to 5 (expert opinion). These criteria were applied to each included study to provide a description of methodological quality. The results of these assessments are shown in table 2.

Table 1 Electronic database search results

Search term	Database PubMed	EBSCO
'Concussion prevention equipment'	208	8
'Concussion prevention training'	180	0
'Concussion prevention education'	158	19

The number of citations found for each search term in both databases are shown above.

Box 1 Inclusion and exclusion criteria

Inclusion criteria:
1. Prospective study design.
2. Studies must report data on and examine the preventative effect of equipment, training or educational programmes on the incidence of concussions in comparison to a control group.

Exclusion criteria:
1. Laboratory-based studies.
2. Further analyses on previously reported prospective studies.
3. Studies written in languages other than English.
4. Abstracts and review papers.

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*[14] 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,[14–21] and a pooled estimate was presented in a forest plot. In addition, the results from seven studies evaluating interventional protective equipment were combined,[14–17 19–21] and a pooled estimate is presented in a forest plot. Heterogeneity was assessed using the I^2 statistic.

Superficial head injury

Studies that reported population sizes and the number of head injuries, including superficial injuries (lacerations, abrasions,

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

Paper	Year	Level of evidence	Total PEDro score	1	2	3	4	5	6	7	8	9	10	11
Barbic *et al*[15]	2005	1b	6	1	1	–	1	–	–	–	1	1	1	1
Benson *et al*[16]	1999	2b	4	1	–	–	1	–	–	–	1	–	1	1
Collins *et al*[17]	2006	2b	3	1	–	–	–	–	–	–	1	–	1	1
Hollis *et al*[22]	2009	2b	3	1	–	–	–	–	–	–	1	–	1	1
Kemp *et al*[23]	2008	2b	3	1	–	–	–	–	–	–	1	–	1	1
Kerr *et al*[18]	2015	2b	4	1	–	–	–	–	–	–	1	1	1	1
Labella *et al*[26]	2002	2b	2	1	–	–	–	–	–	–	1	–	1	–
Marshall *et al*[24]	2005	2b	3	1	–	–	–	–	–	–	1	–	1	1
McGuine *et al*[19]	2014	2b	3	1	–	–	–	–	–	–	1	–	1	1
McIntosh	2001	2b	5	1	1	–	–	–	–	–	1	1	1	1
McIntosh and McCrory[25]	2009	1b	5	1	1	–	1	–	–	–	–	1	1	1
Stuart *et al*[28]	2002	2b	2	1	–	–	–	–	–	–	–	–	1	1
Thompson *et al*[14]	1996	3b	3	1	–	–	–	–	–	–	1	–	1	1
Winters and DeMont[21]	2014	2b	3	1	1	–	–	–	–	–	1	–	1	–
Wisniewski *et al*[27]	2004	2b	3	1	–	–	–	–	–	–	1	–	1	1

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.

contusions), in groups with and without interventional protective equipment were also analysed using random-effects relative risk meta-analysis. McIntosh *et al*[20] 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 I^2 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 17 20 22–25] 8 evaluated mouthguards,[15 19 21–24 26 27] two evaluated hockey face shields[16 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 17–19 21 27] two evaluated hockey,[16 28] one evaluated basketball[26] 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,[25] 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 interventional 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).[18 22–28] 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.[12] Protective equipment, including headgear,

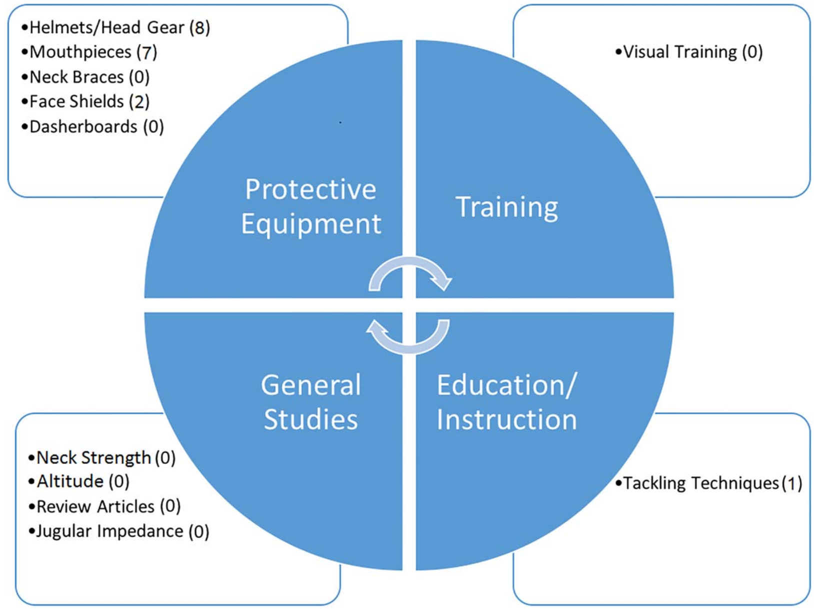

Figure 1 Categories of included articles. Three of the included studies evaluated both mouthguards and headgear.[22–24] The present report included only prospective, controlled trials that compared groups of participants utilising interventional methods for concussion prevention against groups of participants using either the current standard concussion prevention method or none at all. Retrospective and laboratory-based studies on concussion prevention, including those studies that evaluated protective equipment, were excluded. A number of the included studies did not report data necessary for aggregation. Studies that reported population sizes and the number of concussions in groups with and without interventions were combined in meta-analyses as outlined in the text above.

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

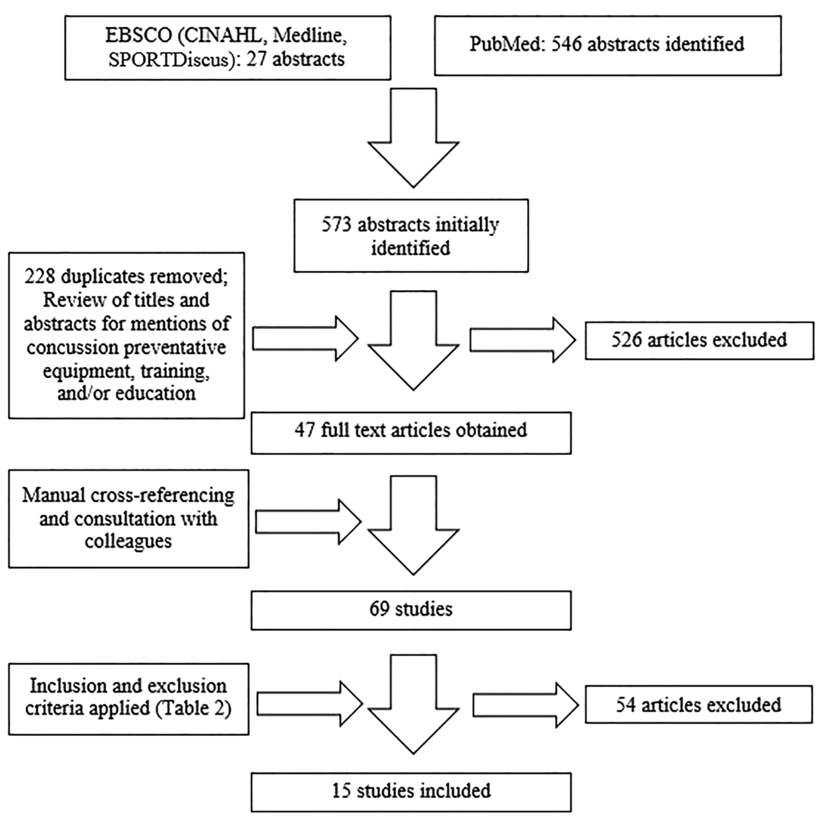

Figure 2 Flow chart summary of the literature search process.

Table 3 Study population, design characteristics, equipment item, and intervention and control arm data

Paper	Year	Sport	Randomised (Y/N)	Exposure data	Type of exposures	INT group	INT population size	INT concussions	INT crude concussion rate	Concussion incidence per 1000 exposures	CTRL group	CTRL population size	CTRL concussions	CTRL crude concussion rate	Concussion incidence per 1000 exposures	Incidence ratio (EXP/CTRL)
Barbic *et al*[15]	2005	American Football and Rugby	Y	N	NR	WIPSS Brain-Pad MG	308	22	0.07	NR	Standard MG	306	21	0.07	NR	NR
Benson *et al*[16]	1999	Hockey	N	Y	Practices/games	Full face shield	319	38	0.12	1.57	Half face shield	323	41	0.13	1.53	1.03
Collins *et al*[17]	2006	American Football	N	N	NR	Revolution helmet	1173	62	0.05	NR	Standard helmet	968	74	0.08	NR	NR
Hollis *et al*[22]	2009	Rugby	N	Y	Player game hours	Always wore HG Always wore MG	671 1735	NR NR	NR NR	7.39 7.45	Never wore HG Never wore MG	985 236	NR NR	NR NR	7.48 8.62	0.99 0.86
Kemp *et al*[23]	2008	Rugby	N	Y	Player game hours	MG HG	NR NR	75 7	NR NR	4 2	No MG No HG	NR NR	17 85	NR NR	5.8 4.6	0.69 0.43
Kerr *et al*[18]	2015	American Football	N	Y	Practices/games	HUF+PW	2108	23	0.02	NR	No HUF	704	22	0.03	NR	NR
Labella *et al*[26]	2002	Basketball	N	Y	Practices/games	MG	NR	3	NR	0.35	No MG	NR	34	NR	0.55	0.64
Marshall *et al*[24]	2005	Rugby	N	Y	Practices/games	MG HG	*NR *NR	*NR *NR	NR NR	NR NR	No MG No HG	*NR *NR	*NR *NR	NR NR	NR NR	NR NR
McGuine *et al*[19]	**2014**	American Football	**N**	**Y**	Practices/games	Custom or specialised MG	901	99	0.11	NR	Standard MG	1386	107	0.08	NR	NR
McIntosh and McCrory[25]	2001	Rugby	Y	Y	Games	HG	NR	7	NR	5.94	No HG	NR	2	NR	5.6	1.06
McIntosh[20]	2009	Rugby	Y	Y	Player game hours	Modified HG Standard HG	1474 1128	80 52	0.05 0.05	7.5 6.4	No HG No HG	1493 1493	67 67	0.04 0.04	6.7 6.7	1.12 0.96
Stuart *et al*[28]	2002	Hockey	N	Y	Player game hours	Half face shield Full face shield	NR NR	5 2	NR NR	8.2 2.9	No face shield No face shield	NR NR	4 4	NR NR	12.2 12.2	0.67 0.24
Thompson *et al*[14]	1996	Bicycling	N	N	NR	Helmet	1718	62	0.04	NR	No helmet	1672	141	0.08	NR	NR
Winters and DeMont[21]	2014	American Football	Y	N	NR	Custom MG	220	8	0.04	NR	Standard MG	192	16	0.08	NR	NR
Wisniewski *et al*[27]	2004	American Football	N	Y	Practices/games	Custom MG	NR	169	NR	0.99	Standard MG	NR	200	NR	1.10	0.9

*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.

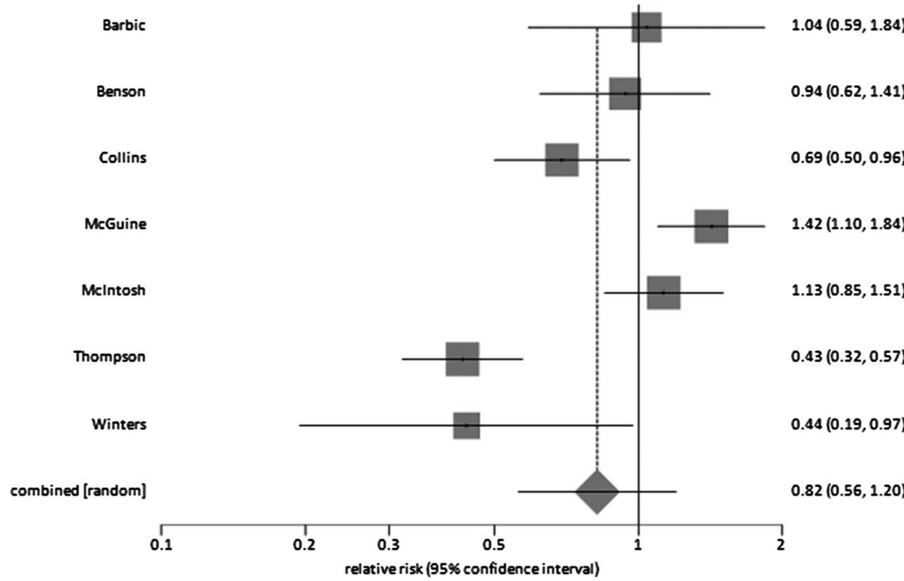

Figure 3 Individual and pooled estimates of relative risk for concussion in participants who wore interventional protective equipment relative to those who wore standard or no equipment.

other collision sports (eg, ice hockey, football).[22 23] Approximately 25% of injuries sustained during rugby are head injuries, with about 10% of injuries being concussions,[20 22 29 30] which occur at rates between 0.62 and 9.1/1000 player game hours.[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.[20 33] Existing evidence indicates that this headgear may have a limited impact on reducing concussion incidence during rugby.[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.[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.[24 25 34] In examination of 'modified headgear' (made with 16 mm thick, 60 kg/m^3 polyethylene foam vs 10 mm thick, 45 kg/m^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.[20] Conversely, other investigations have reported decreased concussion incidence rates among those wearing headgear compared with those who did not.[22 23]

These findings are complicated by *risk compensation*, a strategy involving increasingly reckless play by those wearing protective equipment.[35] A study of <16-year-old male rugby players reported that players believe they can tackle harder and more confidently while wearing headgear.[36] This behaviour modification may negate some or all of the potential concussion-preventing benefits provided by headgear. In addition, Hollis *et al*[22] noted that 'fewer risk takers wore headgear'

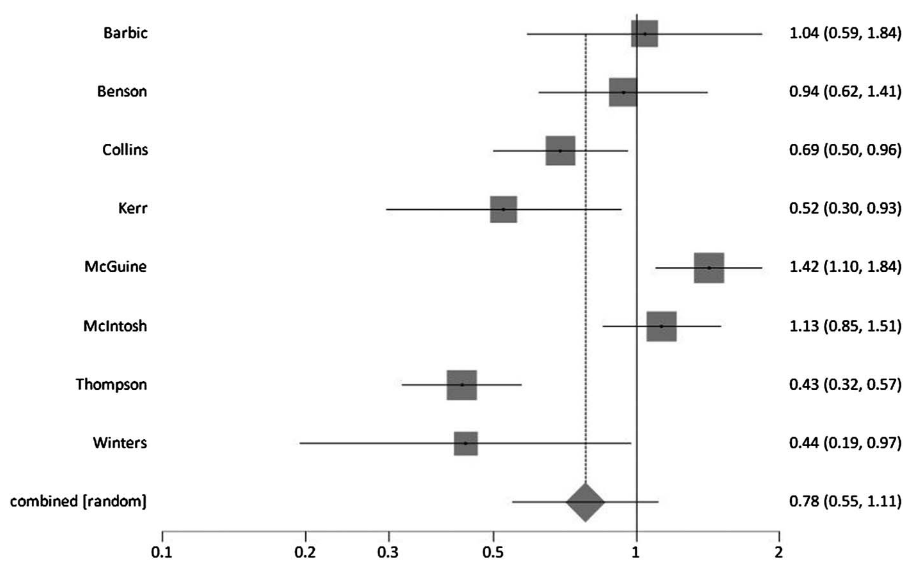

Figure 4 Individual and pooled estimates of relative risk for concussion in participants in interventional study groups relative to those in control study groups. This estimate includes the study that evaluated the effect of an educational programme on concussion incidence in American football.[18]

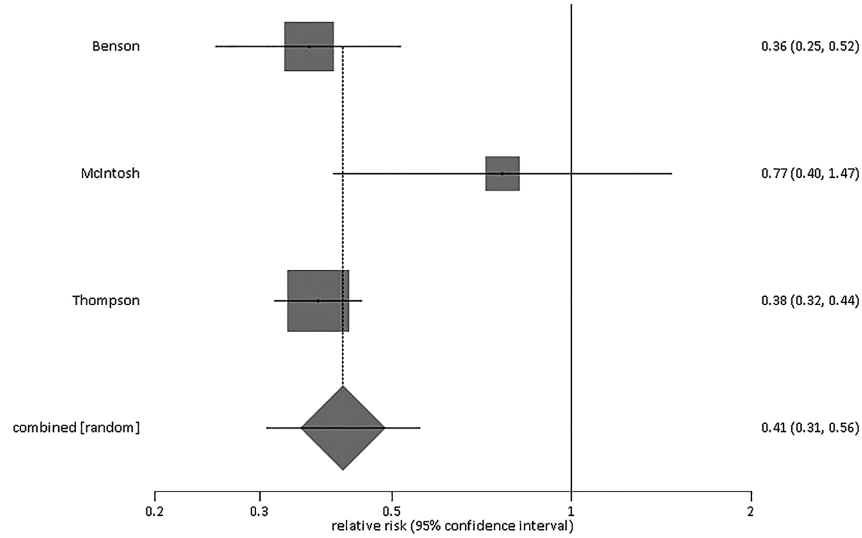

Figure 5 Individual and pooled estimates of relative risk for superficial head injury (not including concussion) in participants who wore interventional protective equipment relative to those who wore standard or no equipment.

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,[24] and two studies reported adjusted rate ratios accounting for previous injury.[22 24] The remaining three studies may have underestimated true concussion incidence by not considering these variables.[20 23 25]

Although the evidence on headgear and concussion prevention remains unclear, headgear has been used within rugby with increasing frequency recently.[37] 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.[38] Results on this topic among the included studies are mixed, with Marshall *et al*[24] reporting similar results but with McIntosh *et al*[20] reporting no significant differences in superficial head injuries between those with headgear and those without. However, McIntosh *et al*[20] 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 via an increased number of school-aged players.[39] These young players are at increased risk relative to older peers.[22] This underscores the importance of continuing to evaluate equipment and other means to prevent concussions in this population to reduce the long-term morbidity associated with TBIs. Conversely, recent trends in amateur boxing have been towards the removal of headgear/headguards from competition, as reflected in the recent rules change by the IOC.[40] No prospective trials have evaluated the efficacy of boxing headgear in preventing concussions, and laboratory studies vary widely in their methods.[41] Future prospective trials are warranted to determine if headgear can decrease concussion or superficial head injury incidence in boxing and other combat sports.

Helmets have long been implemented for protection from head and brain injury by a wide range of users, from casual athletes to professional pilots.[42–44] A helmet, if designed properly, has potential to prevent head injury by distributing the force of an impact over a greater surface area of the wearer's head, thus diminishing the trauma received by the user.[45 46] Wearing a helmet may be the simplest way for a cyclist to avoid a head injury.[47 48] The included study performed by Thompson *et al*[14] lends credence to this claim, as the authors reported that those who wore helmets sustained fewer head injuries (OR=0.32). 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,[22 37] some cyclists may feel that the protection afforded by helmets allows them to ride more aggressively.[49] Conversely, certain cyclists wear helmets more often simply by nature of being more cautious riders.[50]

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.[51–58] 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.[59–61] 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,[62] many of which occur at the crown of the helmet and at oblique angles on the helmet facemask.[61] Collins *et al*[17] 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.[63]

Although these studies show that better helmet technology reduced concussion occurrence in football players,[17 62 63] since the time of their publishing these helmet models (and newer models with improved technology) have become the standard level of equipment,[64] yet concussion rates remain high.[1 12 65] In addition, in a recent study of over 1300 high school football players, concussion risk did not change based on helmet age or brand/model.[19] 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.[26 66–71] 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.[15 72 73] 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.[21] Labella *et al*[26] 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.[15] Three of the included studies have examined the potential benefits of advanced and custom mouthguards over more common over-the-counter mouthguards.[15 21 27] Barbic *et al*[15] 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*[27] 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,[23 24] with one of the studies actually reporting increased incidence in mouthguard wearers.[24] This increased incidence of concussion was also reported in high school football athletes wearing custom or specialised mouthguards.[19] 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.[21] 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,[21 74] while others conclude there is no difference between mouthguard types.[26 75]

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,[21] 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,[15 21] and the potential for under-reporting of injuries by team athletic trainers is a considerable limitation.[15 27] 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.[27] 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.[76] Concussion is the most common head injury in ice hockey, with incidence ranging from 0.24 to 8.2 cases per 1000 exposures.[16 28 77] Face shields gained popularity as a result of their efficacy at reducing the incidence of facial and eye injuries.[78] 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.[79] Benson *et al*[16] 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.[16] 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.[28] 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.[28] The National Collegiate Athletic Association now mandates full facial protection be worn by all players,[44] while junior A players may sign a waiver at age 18 that enables them to wear a half shield.[80] The International Ice Hockey Federation (IIHF), the governing body for the Olympics, mandates half shields for men and full shields for women.[81] 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.[18] 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 5–15 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.[82 83] 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.[83] 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.[87] 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.[15] 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 al*[19] 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 al*[20] 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 al*[18] 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 al*[17] 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.[7] 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,[12] 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.

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REFERENCES

1 Daneshvar DH, Nowinski CJ, McKee AC, *et al*. The epidemiology of sport-related concussion. *Clin Sports Med* 2011;30:1–17, vii.
2 Fridman L, Fraser-Thomas JL, McFaull SR, *et al*. Epidemiology of sports-related injuries in children and youth presenting to Canadian emergency departments from 2007–2010. *BMC Sports Sci Med Rehabil* 2013;5:30.
3 McCrory P, Meeuwisse W, Aubry M, *et al*. Consensus statement on Concussion in Sport—the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *J Sci Med Sport* 2013;16:178–89.
4 Karlin AM. Concussion in the pediatric and adolescent population: "different population, different concerns". *PM R* 2011;3(Suppl 2):S369–79.
5 Colvin AC, Mullen J, Lovell MR, *et al*. The role of concussion history and gender in recovery from soccer-related concussion. *Am J Sports Med* 2009;37:1699–704.
6 Brown NJ, Mannix RC, O'Brien MJ, *et al*. Effect of cognitive activity level on duration of post-concussion symptoms. *Pediatrics* 2014;133:e299–304.
7 Meehan WP, O'Brien MJ. Sports-related Concussion in Children and Adolescents: Management. In TW Post, AC Hergenroeder, RG Bachur, & JF Wiley II (Eds), UptoDate. 2015. Available from http://www.uptodate.com/contents/concussion-in-children-and-adolescents-management
8 Rabadi MH, Jordan BD. The cumulative effect of repetitive concussion in sports. *Clin J Sport Med* 2001;11:194–8.
9 Chrisman SP, Schiff MA, Rivara FP. Physician concussion knowledge and the effect of mailing the CDC's "Heads Up" toolkit. *Clin Pediatr (Phila)* 2011;50:1031–9.
10 Meehan WP III, Bachur RG. Sport-related concussion. *Pediatrics* 2009;123:114–23.
11 Daneshvar DH, Baugh CM, Nowinski CJ, *et al*. Helmets and mouth guards: the role of personal equipment in preventing sport-related concussions. *Clin Sports Med* 2011;30:145–63, x.
12 TBI: Get the Facts. Centers for Disease Control and Prevention. 2016. http://www.cdc.gov/traumaticbraininjury/get_the_facts.html (accessed 12 Sep2015).
13 Patton DA, McIntosh A. Considerations for the performance requirements and technical specifications of soft-shell padded headgear. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*; 2015.
14 Thompson DC, Rivara FP, Thompson RS. Effectiveness of bicycle safety helmets in preventing head injuries. A case-control study. *JAMA* 1996;276:1968–73.
15 Barbic D, Pater J, Brison RJ. Comparison of mouth guard designs and concussion prevention in contact sports: a multicenter randomized controlled trial. *Clin J Sport Med* 2005;15:294–8.
16 Benson BW, Mohtadi NG, Rose MS, *et al*. Head and neck injuries among ice hockey players wearing full face shields vs half face shields. *JAMA* 1999;282:2328–32.
17 Collins M, Lovell MR, Iverson GL, *et al*. Examining concussion rates and return to play in high school football players wearing newer helmet technology: a three-year prospective cohort study. *Neurosurgery* 2006;58:275–86; discussion 75–86.
18 Kerr ZY, Yeargin S, Valovich McLeod TC, *et al*. Comprehensive coach education and practice contact restriction guidelines result in lower injury rates in youth American football. *Orthop J Sports Med* 2015;3:2325967115594578.
19 McGuine T, Hetzel S, McCrea M, *et al*. Protective equipment and player characteristics associated with the incidence of sport-related concussion in high school football players: a multifactorial prospective study. *Am J Sports Med* 2014;42:2470–8.
20 McIntosh AS, McCrory P, Finch CF, *et al*. Does padded headgear prevent head injury in rugby union football? *Med Sci Sports Exerc* 2009;41:306–13.
21 Winters J, DeMont R. Role of mouthguards in reducing mild traumatic brain injury/concussion incidence in high school football athletes. *Gen Dent* 2014;62:34–8.
22 Hollis SJ, Stevenson MR, McIntosh AS, *et al*. Incidence, risk, and protective factors of mild traumatic brain injury in a cohort of Australian nonprofessional male rugby players. *Am J Sports Med* 2009;37:2328–33.
23 Kemp SP, Hudson Z, Brooks JH, *et al*. The epidemiology of head injuries in English professional rugby union. *Clin J Sport Med* 2008;18:227–34.
24 Marshall SW, Loomis DP, Waller AE, *et al*. Evaluation of protective equipment for prevention of injuries in rugby union. *Int J Epidemiol* 2005;34:113–18.
25 McIntosh AS, McCrory P. Effectiveness of headgear in a pilot study of under 15 rugby union football. *Br J Sports Med* 2001;35:167–9.
26 Labella CR, Smith BW, Sigurdsson A. Effect of mouthguards on dental injuries and concussions in college basketball. *Med Sci Sports Exerc* 2002;34:41–4.
27 Wisniewski JF, Guskiewicz K, Trope M, *et al*. Incidence of cerebral concussions associated with type of mouthguard used in college football. *Dent Traumatol* 2004;20:143–9.
28 Stuart MJ, Smith AM, Malo-Ortiguera SA, *et al*. A comparison of facial protection and the incidence of head, neck, and facial injuries in junior A hockey players. A function of individual playing time. *Am J Sports Med* 2002;30:39–44.
29 Davidson RM. Schoolboy rugby injuries, 1969–1986. *Med J Aust* 1987;147:119–20.
30 Targett SG. Injuries in professional Rugby Union. *Clin J Sport Med* 1998;8:280–5.
31 Koh JO, Cassidy JD, Watkinson EJ. Incidence of concussion in contact sports: a systematic review of the evidence. *Brain Inj* 2003;17:901–17.
32 Cassidy JD, Carroll LJ, Peloso PM, *et al*. Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. *J Rehabilit Med* 2004;36:28–60.
33 Board IR. *The laws of the game, Rugby Union*. Dublin, Ireland: Board IR, 2007.
34 McIntosh AS, McCrory P. Impact energy attenuation performance of football headgear. *Br J Sports Med* 2000;34:337–41.
35 Hagel B, Meeuwisse W. Risk compensation: a "side effect" of sport injury prevention? *Clin J Sport Med* 2004;14:193–6.
36 Finch CF, McIntosh AS, McCrory P. What do under 15-year-old schoolboy rugby union players think about protective headgear? *Br J Sports Med* 2001;35:89–94.
37 McIntosh AS, McCrory P, Finch CF, *et al*. Rugby headgear study. *J Sci Med Sport* 2003;6:355–8.
38 Jones SJ, Lyons RA, Evans R, *et al*. Effectiveness of rugby headgear in preventing soft tissue injuries to the head: a case-control and video cohort study. *Br J Sports Med* 2004;38:159–62.
39 Union AR. *Community rugby report, national participation figures (2003–2008)*. Annual Report, 2008:65.
40 Wang SS. Boxing Group Bans Headgear to Reduce Concussions. *The Wall Street Journal* 14 March 2013.
41 McIntosh AS, Patton DA. The impact performance of headguards for combat sports. *Br J Sports Med* 2015;49:1113–17.
42 Durr N, Bassette AB. Sports helmet: Google Patents, 2000.
43 Wasserman RC, Buccini RV. Helmet protection from head injuries among recreational bicyclists. *Am J Sports Med* 1990;18:96–7.
44 Norman RW, Bishop PJ, Pierrynowski MR, *et al*. Aircrew helmet protection against potential cerebral concussion in low-magnitude impacts. *Aviat Space Environ Med* 1979;50:553–61.
45 Thompson DC, Rivara FP, Thompson R. Helmets for preventing head and facial injuries in bicyclists. *Cochrane Database Syst Rev* 2000;(2):CD001855.
46 Liu BC, Ivers R, Norton R, *et al*. Helmets for preventing injury in motorcycle riders. *Cochrane Database Syst Rev* 2008;(1):CD004333.
47 Henderson M. *The effectiveness of bicycle helmets: a review*. Sydney, Australia: Wales TMAAoNS, 1996
48 Thompson DC, Dannenberg AL, Thompson RS, *et al*. *Bicycling*. Champaign, IL: Human Kinetics Publishing, 1996.
49 Hillman M. *Cycle helmets: the case for and against*. London, England: Policy Studies Institute; 1993.

50 Spaite DW, Murphy M, Criss EA, *et al*. A prospective analysis of injury severity among helmeted and nonhelmeted bicyclists involved in collisions with motor vehicles. *J Trauma* 1991;31:1510–16.
51 Cantu R. Primary care of the injured athlete, part I. *Clin Sports Med* 1997;16:531–42.
52 Echemendia RJ, Julian LJ. Mild traumatic brain injury in sports: neuropsychology's contribution to a developing field. *Neuropsychol Rev* 2001;11:69–88.
53 Kelly JP. Concussion in sports and recreation. *Semin Neurol* 2000;20:165–71.
54 Kelly JP, Rosenberg JH. The development of guidelines for the management of concussion in sports. *J Head Trauma Rehabil* 1998;13:53–65.
55 Kelly JP, Rosenberg JH. Diagnosis and management of concussion in sports. *Neurology* 1997;48:575–80.
56 Lovell MR, Collins MW. Neuropsychological assessment of the college football player. *J Head Trauma Rehabil* 1998;13:9–26.
57 Matser EJ, Kessels AG, Lezak MD, *et al*. Acute traumatic brain injury in amateur boxing. *Phys Sportsmed* 2000;28:87–92.
58 Powell JW, Barber-Foss KD. Traumatic brain injury in high school athletes. *JAMA* 1999;282:958–63.
59 Kerr ZY, Collins CL, Mihalik JP, *et al*. Impact locations and concussion outcomes in high school football player-to-player collisions. *Pediatrics* 2014;134:489–96.
60 Scott Delaney J, Puni V, Rouah F. Mechanisms of injury for concussions in university football, ice hockey, and soccer: a pilot study. *Clin J Sport Med* 2006;16:162–5.
61 Pellman EJ, Viano DC, Tucker AM, *et al*. Concussion in professional football: location and direction of helmet impacts-part 2. *Neurosurgery* 2003;53:1328–40; discussion 40–1.
62 Viano DC, Pellman EJ, Withnall C, *et al*. Concussion in professional football: performance of newer helmets in reconstructed game impacts—part 13. *Neurosurgery* 2006;59:591–606; discussion 591–606.
63 Rowson S, Duma SM, Greenwald RM, *et al*. Can helmet design reduce the risk of concussion in football? *J Neurosurg* 2014;120:919–22.
64 Viano DC, Halstead D. Change in size and impact performance of football helmets from the 1970s to 2010. *Ann Biomed Eng* 2012;40:175–84.
65 Benson BW, McIntosh AS, Maddocks D, *et al*. What are the most effective risk-reduction strategies in sport concussion? *Br J Sports Med* 2013;47:321–6.
66 Stenger JM, Lawson EA, Wright JM, *et al*. Mouthguards: protection against shock to head, neck and teeth. *J Am Dent Assoc* 1964;69:273–81.
67 Hickey JC, Morris AL, Carlson LD, *et al*. The relation of mouth protectors to cranial pressure and deformation. *J Am Dent Assoc* 1967;74:735–40.
68 Chapman P. Concussion in contact sports and the importance of mouthguards in protection. *Aust J Sci Med Sport* 1985;3:170–4.
69 Ommaya AK. Head injury mechanisms and the concept of preventive management: a review and critical synthesis. *J Neurotrauma* 1995;12:527–46.
70 Delaney JS, Lacroix VJ, Leclerc S, *et al*. Concussions among university football and soccer players. *Clin J Sport Med* 2002;12:331–8.
71 Benson BW, Rose MS, Meeuwisse WH. The impact of face shield use on concussions in ice hockey: a multivariate analysis. *Br J Sports Med* 2002;36:27–32.
72 Center HIPaR. Recreational injury interventions: mouthguards. Secondary recreational injury interventions: mouthguards. https://depts.washington.edu/hiprc/practices/topic/recreation/sportsmouth-guards.html
73 Johnsen DC, Winters JE. Prevention of intraoral trauma in sports. *Dent Clin North Am* 1991;35:657–66.
74 Winters JE Sr. Commentary: role of properly fitted mouthguards in prevention of sport-related concussion. *J Athl Train* 2001;36:339–41.
75 Blignaut JB, Carstens IL, Lombard CJ. Injuries sustained in rugby by wearers and non-wearers of mouthguards. *Br J Sports Med* 1987;21:5–7.
76 Stuart MJ, Smith AM, Nieva JJ, *et al*. Injuries in youth ice hockey: a pilot surveillance strategy. *Mayo Clin Proc* 1995;70:350–6.
77 Tuominen M, Stuart MJ, Aubry M, *et al*. Injuries in women's international ice hockey: an 8-year study of the World Championship tournaments and Olympic Winter Games. *Br J Sports Med* Published Online First: 7 Jul 2015 doi:10.1136/bjsports-2015-094647
78 Pashby T. Eye injuries in Canadian amateur hockey. *Can J Ophthalmol* 1985;20:2–4.
79 Tator CH, Carson JD, Edmonds VE. New spinal injuries in hockey. *Clin J Sport Med* 1997;7:17–21.
80 Directors UHBo. *2013–2017 Official Rules of Ice Hockey Junior Hockey Edition*. Colorado Springs, Colorado: USA Hockey, 2013:90.
81 Federation IIH. *IIHF Official Rule Book 2014–2018*. 2nd edn. Zurich: IIHF, 2015:148.
82 Collins CL, Fletcher EN, Fields SK, *et al*. Neck strength: a protective factor reducing risk for concussion in high school sports. *J Prim Prev* 2014;35:309–19.
83 Barrett MD, McLoughlin TF, Gallagher KR, *et al*. Effectiveness of a tailored neck training program on neck strength, movement, and fatigue in under-19 male rugby players: a randomized controlled pilot study. *Open Access J Sports Med* 2015;6:137–47.
84 Mansell J, Tierney RT, Sitler MR, *et al*. Resistance training and head-neck segment dynamic stabilization in male and female collegiate soccer players. *J Athl Train* 2005;40:310–19.
85 Swartz EE, Broglio SP, Cook SB, *et al*. Early Results of a Helmetless-Tackling Intervention to Decrease Head Impacts in Football Players. *J Athl Train* 2015;50:1219–22.
86 Clark JF, Colosimo A, Ellis JK, *et al*. Vision Training Methods for Sports Concussion Mitigation and Management. *JoVE (Journal of Visualized Experiments)* 2015;99:e52648–e48.
87 Mozes A. New 'Collar' Aims to Help Shield Brain From Concussion. New 'Collar' Aims to Help Shield Brain From Concussion. 2015. https://consumer.healthday.com/cognitive-health-information-26/brain-health-news-80/new-collar-aims-to-help-shield-brain-from-concussion-705476.html (accessed 16 Dec2016).
88 Smith DW, Bailes JE, Fisher JA, *et al*. Internal jugular vein compression mitigates traumatic axonal injury in a rat model by reducing the intracranial slosh effect. *Neurosurgery* 2012;70:740–6.
89 Turner RC, Naser ZJ, Bailes JE, *et al*. Effect of slosh mitigation on histologic markers of traumatic brain injury: laboratory investigation. *J Neurosurg* 2012;117:1110–18.
90 Smith DW, Myer GD, Currie DW, *et al*. Altitude modulates concussion incidence: implications for optimzing brain compliance to prevent brain injury in athletes. *Orthop J Sports Med* 2013;16:1–7.
91 Myer GD, Smith D, Barber Foss KD, *et al*. Rates of concussion are lower in National Football League games played at higher altitudes. *J Orthop Sports Phys Ther* 2014;44:164–72.
92 PEDro. scale (English). PEDro: Physiotherapy Evidence Database. 2015. http://www.pedro.org.au/english/downloads/pedro-scale/ (accessed 12 Sep2015).

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

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