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Risk factors for sports concussion: an evidence-based systematic review

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ABSTRACT

Concussion is a common sports injury with approximately 1.6–3.8 million sport-related concussions reported in the USA annually. Identifying risk factors may help in preventing these injuries. This systematic review aims to identify such risk factors. Three electronic databases; ScienceDirect, PubMed and SpringerLink, were searched using the keywords 'RISK FACTORS' or 'PREDISPOSITION' in conjunction with 'SPORT' and 'CONCUSSION'. Based on the inclusion and exclusion criteria, 13 628 identified titles were independently analysed by two of the authors to a final list of 86 articles. Only articles with a level of evidence of I, II and III were included according to robust study design and data analysis. The level of certainty for each risk factor was determined. A high level of certainty for increased risk of a subsequent concussion in athletes sustaining more than one previous concussion was reported in 10 of 13 studies. Further, a high level of certainty was assigned to match play with all 29 studies reporting an increased concussion risk during matches. All other risk factors were evaluated as having a low level of certainty. Although several risk factors were identified from the appraised studies, prospective cohort studies, larger sample sizes, consistent and robust measures of risk should be employed in future research.

INTRODUCTION

Approximately 1.6–3.8 million concussions reported in the USA are attributed to sports participation.¹ Concussion, as defined in the Zurich 2012 consensus statement, is a pathophysiological process resulting in functional neurological impairments, as a consequence of forceful biomechanical impacts directly on or transmitted to the head, neck or face.² Deficits in cognitive, behavioural and motor control normally persist from 24 h to 10 days after injury.^{2–3} Individuals who sustain repeat concussions may experience long-term and severe damage such as chronic traumatic encephalopathy (CTE),⁴ decreased mental speed⁵ or memory dysfunction.⁶

Research suggests that concussion risk may be modulated by several factors. Studies often report sports concussion occurring more frequently in women, younger athletes and those with a history of previous concussion.^{7–10} However, the exact aetiology of concussion is unclear. The identification of risk factors, which predispose an athlete to concussion, may further our understanding of the underlying mechanisms of concussion and aid in the improvement of prevention strategies. Moreover, recent articles highlight CTE as a potentially significant consequence of repeated head

trauma in contact sports^{4 11 12} making the prevention of concussion much more important. Therefore, the aim of this evidence-based systematic review is to provide a descriptive summary of the literature, highlight potential risk factors for concussion and further our knowledge of concussion susceptibility.

METHODS

Search strategy

Published articles that examined potential risk factors for sport-related concussion were reviewed following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.¹³ Three electronic databases, ScienceDirect, PubMed and SpringerLink, were searched using the keywords 'RISK', 'RISK FACTOR' or 'PREDISPOSITION' in conjunction with 'SPORT' and 'CONCUSSION'. The database search was limited to articles published between January 1980 and April 2013. Review articles and book chapters were initially included to provide a larger selection of articles from the reference lists. A three-step method was followed to identify the articles that were reviewed. The titles, abstracts and full texts were independently screened by two of the authors (SA and SM). Articles were excluded at each step if they were unrelated to the topic or met the exclusion criteria outlined in box 1.

Two rounds of reviewing the literature, using the three-step method in each round, were performed. Round 1 pertained to the review of articles from the search results of the databases and round 2 involved reviewing the reference lists of identified articles from round 1. Thereafter, the identified articles from rounds 1 and 2 were stringently appraised according to the inclusion criteria summarised in box 2.

Data extraction

The study design, study population and results were reviewed from the identified articles in the appraisal step. Studies reporting risk estimates including relative risk (RR), odds ratio (OR), incidence rate ratio (IRR) and hazard ratio (HR) were identified. These risk estimates are routinely used as measures of injury risk.^{14 15} In the case in which studies had not reported these measures, the IRR including 95% confidence interval (CI) was calculated¹⁶ by two of the authors (SA and SM) and denoted as IRR*. Similarly, in cases where stylistically appropriate, the inverse of the risk estimate and CI were calculated and an asterisk was assigned. Notably, certain studies reporting a χ^2 p value only were included in the appraisal as it is a

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Box 1 A summary of the exclusion criteria applied by two of the authors (SA and SM) to identify relevant articles

Exclusion criteria

1. Commentaries, letters, editorials, conference proceedings, case reports, conference abstracts or non-peer reviewed articles.
2. Studies examining non sport-related concussions.
3. Studies which only include concussions when a loss of consciousness occurred.
4. Studies of severe traumatic brain injury (eg, fractures, lesions).
5. Studies of animal or biomechanical models of brain injury.

measure of statistical significance but is limited in interpretation and estimation of risk.

Level of evidence and certainty

The level of evidence was determined for each article selected by the inclusion and exclusion criteria. The level of evidence is a ranking system for research articles and was determined by two of the authors (SA and SM) using previously described definitions (table 1).^{17–19} Only articles with a level of evidence of I, II and III were included in the final appraisal step.

Subsequently, articles investigating the same risk factor were grouped and, from an overall analysis of the articles, the level of certainty that each risk factor is associated with increased risk of concussion was calculated. The definitions used to determine low, moderate and high level of certainty, as originally defined by the US Preventative Services Task Force²⁰ and modified by Posthumus *et al*¹⁷ are detailed in table 2.

RESULTS AND DISCUSSION

The article selection process is outlined in figure 1. In total, the analyses of the 86 appraised studies identified 14 intrinsic and extrinsic risk factors for sports concussion which are discussed below and summarised in table 3 and online supplementary Tables S1.

Previous concussion

A history of previous concussion was measured as one or more sports concussions sustained prior to the observation period of the specific study. Ten of the 13 studies reported an increased

Box 2 The inclusion criteria used to select articles to be incorporated in the systematic review

Inclusion criteria

1. The article must include original data.
2. The article must be published in English or have been translated into English.
3. The article must include a minimum of one potential risk factor for sport concussion.
4. The article must include a point or risk estimate (eg, OR), with the 95% CI and/or p value obtained from χ^2 tests, or the necessary data to calculate these measures of association.

Table 1 Level of evidence (I–V) definitions used for study evaluation, as previously defined^{17 18}

Level of Evidence	Study types
I	Randomised controlled trials and high-quality (large sample sizes, robust methodology) prospective cohort studies
II	Lower quality (small sample sizes, weaker methodology) prospective and retrospective cohort studies
III	Case-control
IV	Case series
V	Expert opinions

risk of concussion in those athletes with a history of previous concussion^{21–33} (see online supplementary table S1.1).

Four studies reported an increased risk of concussion in junior ice hockey players who had a history of previous concussions.^{21–23 27} Similarly, a greater risk was also observed in rugby union players with one or more than two previous concussions.²⁶ Studies investigating the risk of previous concussions in American football^{24 25 28 29} observed a threefold to sixfold increased risk in sustaining a subsequent concussion. Furthermore, a cohort of athletes participating in various sports with at least one previous concussion were at a threefold greater risk of sustaining a concussion compared with those who had no previous concussion.³⁰ However, a small number of concussions were reported (n=28), which constrains the interpretation of the results.

Three studies of American football and soccer players showed 2-fold to 11-fold increased odds of sustaining a concussion in those with a history of previous concussion. However, these studies lacked a 95% CI resulting in a meaningless risk estimate and therefore no effect on risk (see online supplementary table S1.1).^{31–33}

All three studies reporting no effect are lower quality retrospective studies (level of evidence of II and III), whereas the 10 studies showing an increased risk were well-designed and high-quality prospective studies with four denoted as level I and the remaining were level II. No studies found a decreased risk. Notably, studies reporting concussion history are often constrained by the unreliability of patient recall, however overall the published studies provide a good estimate of risk and are

Table 2 Level of certainty (high–low) definitions used for risk assessment as previously defined by Sawaya *et al*²⁰ and modified by Posthumus *et al*¹⁷

Level of certainty	Definition
High	The available evidence includes consistent results from level I studies. These studies provide a good estimate of risk and are unlikely to be strongly affected by future studies
Moderate	The available evidence includes sufficient evidence to determine that there is risk associated with the injury, but confidence in the estimate is constrained by factors such as the sample size and quality of studies, as well as inconsistency of findings across individual studies. As more information becomes available, the magnitude of risk could change or even alter the conclusion
Low	The available evidence is insufficient to assess risk. Evidence is insufficient because of the limited number or size of studies, and inconsistency of findings across individual studies. More information may allow an estimation of risk

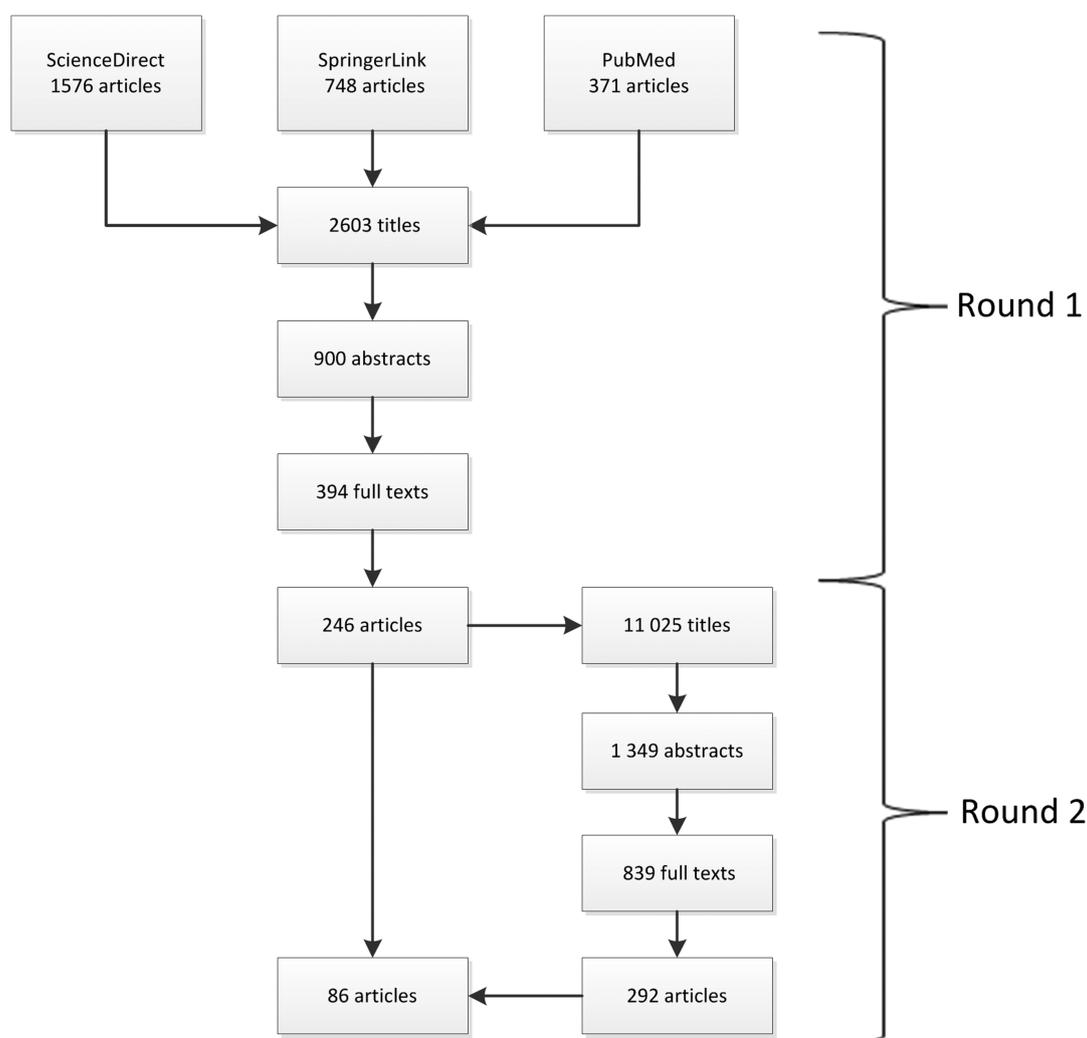


Figure 1 Outline of the literature search procedure and article selection. In round 1 2603 articles were identified using the three electronic database searches. After the title, abstract and full-text screening steps the number of articles was reduced to 900, 394 and 246 articles, respectively. From the reference lists of the 246 full text selected articles, 11 025 articles were extracted. Using the same screening steps as round 1 the 11 025 articles were reduced to 1349 after title, 839 after abstract and 292 after full-text screening. Inclusion and exclusion criteria were applied, as described in the methods, resulting in a final selection of 86 articles which were critically appraised.

unlikely to be affected by future studies. Therefore, a history of previous concussion increases concussion risk with a high level of certainty.

Sex

Twenty-three studies investigated whether there was a difference in concussion risk between male and female athletes (see online supplementary table S1.2). Four studies found men to be at increased risk,^{34–37} 10 studies showed that women had a greater risk of concussion^{33, 38–46} and nine studies found no association.^{47–55}

Men were at a greater risk in youth alpine sports,³⁵ youth American football,³⁶ lacrosse³⁴ and when comparing different sport types.³⁷ However, comparing different sport types, between sexes, introduces a bias as men tend to play high-collision sports with increased concussion risk. Furthermore, men are often more willing to take more risks within the same sport.³⁵ More studies are required to confidently assess sex differences in male-dominated sports, such as rugby and American football.

Women were found to have a 1.5-fold to 2.5-fold greater concussion risk in various levels of soccer.^{33, 38–41, 43–45} Two studies found no significant difference between male and female soccer players^{49, 53} but included only 5 and 29 concussions, respectively, and therefore lacked statistical power. Women had a 1.5-fold and 3-fold higher concussion risk in the five studies on basketball populations.^{38, 39, 42, 43, 46} Four studies compared female softball and male baseball players with three studies reporting greater risk in softball players.^{38, 40, 41, 43} Several possible reasons for increased concussion susceptibility in women have been proposed. Female soccer players have been found to have increased head acceleration during impacts compared with males, indicative of decreased neck strength and effective head mass.^{56, 57} It has been suggested that the increased head to ball ratio in female soccer players may also play a role.⁵⁸ Another reason for higher concussion rates in women may be their increased willingness to report injuries.⁵⁹

Nine studies observed no difference in concussion risk between sexes in taekwondo,^{47, 50, 51} soccer,^{49, 53} collegiate rugby,⁴⁸ lacrosse^{38, 43} and when comparing different sport types.^{52, 54} A possible confounding variable when comparing sex

differences in lacrosse; is the difference in protective equipment and rules with physical contact reduced in the female game.

The results from these studies suggest that in sports where rules and physicality are more equal between sexes, such as soccer and basketball, women appear to be at greater risk. However, when all sports are collectively analysed, there is a low level of certainty that sex is a risk factor for concussion. Future studies should include measures of exposures so that a reliable correlation between sex and concussion risk may be established.

Age

Fourteen studies examined whether concussion risk was modulated by age (see online supplementary table S1.3). Eight studies identified the older age group to be associated with greater concussion risk;^{36 39 52 55 60–63} conversely three studies found the younger age group at greater risk^{50 64 65} and three studies found no effect of age.^{22 55 66}

Collegiate cheerleaders were at a threefold greater concussion risk compared with those younger than 18 years, although only 23 concussions were recorded in 9022 participants.⁶¹ An increased concussion risk in collegiate athletes is not exclusive to cheerleaders. A level III retrospective study, investigating over 3700 sport concussions for several sports, found an increased likelihood of concussion occurring in individuals 10–14 and 15–18 years compared with the younger cohort (5–10 years).⁵² Furthermore, significantly higher concussion rates were observed in 11-year-old to 16-year-old ice hockey players compared with those in the 9–10 year range.⁶² However, this finding is most likely confounded by the effect of body checking only permitted in age groups above 10 years.

In contrast, children younger than 6 years were at greater risk of concussion in roller skating, ice skating and rollerblading.⁶⁵ In a large-scale level I prospective cohort study, including over 1000 concussions, high school football players were at an increased concussion risk compared with collegiate players.⁶⁴

Three studies found no difference in concussion risk between age groups when comparing high school to adult club rugby union⁶⁶ 11–12 to 13–14-year-old ice hockey players²² and male lacrosse high school athletes.⁵⁵

Although more studies reported greater risk in the older cohort, only one of these studies was a high-quality level I³⁹ and the remaining seven were level II or III mainly due to small number of concussions and a weaker study design (see online supplementary table S1.3). The outcomes of the appraised studies indicate that age may play a role in concussion risk; however, contrasting findings confers a low level of certainty for concussion risk.

Genetics

Genetic association studies on concussion risk are limited. The apolipoprotein E (*APOE*) gene is, thus far, the only genetic marker investigated with regard to concussion risk. Only one of the three appraised studies showed an increased concussion risk^{30 67 68} (see online supplementary table S1.4). All three studies investigated the association between the *APOE* gene and concussion. The *APOE* gene encodes for the lipid carrier protein, apo E, which has been implicated in nerve damage.^{69 70} The TT genotype of the –186 bp promoter variant of the *APOE* gene was significantly associated with a history of one or more previous concussions in intercollegiate soccer and American football.⁶⁷ The two studies that observed no association between the *APOE* ε4 allele, concussion history⁶⁸ and multiple concussions³⁰ recorded a small number of concussions.

Therefore, the absence of an association must be interpreted cautiously. Because of the few studies that were available and none with a high level of evidence of I, the genetic risk for concussion was given a low level of certainty.

Behaviour

A preference for aggressive action on the field was used as a measure of athlete behaviour in the four high quality level I and II studies^{22 23 50 71} (see online supplementary table S1.5). Three studies investigated concussion risk and player behaviour in ice hockey, an aggressive collision sport.⁷² Athletes who played ice hockey for tension and aggression relief were significantly more likely to sustain a concussion compared with players with less aggressive tendencies.⁷¹ The other two prospective cohort studies on ice hockey showed no effect of aggressive behaviour preference and experience in an aggressive tactic on concussion risk.^{22 23}

The Korean martial art of taekwondo has developed into a full-contact sport involving permissible contact to the head.⁷³ Taekwondo athletes who used defensive blocking skills during a competition showed a significantly decreased concussion risk.⁵⁰

Although there is an implication for aggressive behaviour (including legal sport actions) increasing concussion risk in sports involving head and neck contact, very few high-quality studies result in a low certainty level assigned to behaviour as a concussion risk.

Match versus practice

All of the 29 studies indicated that there was a higher risk of concussion in matches compared with practices^{25 30 39 40 41 43 48 74–95} (see online supplementary table S1.6). The increased risk of high-impact collisions in match play compared with practices is the primary reason for the increased risk.⁸³ There was a wide range of risk estimate values, which was often due to low numbers of concussions in training sessions skewing the statistics. However, all studies reflected an increased concussion risk in matches and seem unlikely to be altered by future research. Therefore, match play was assigned a high level of certainty to increase concussion risk.

Match period

Two studies examined the period of the match as a potential risk factor for concussion^{96 97} (see online supplementary table S1.7). The first study found there were significantly more concussions in the second compared with the third period in elite ice hockey games.⁹⁶ The second study found no difference in concussion rates between the first and second halves of professional rugby league football.⁹⁷ Due to the limited number of studies available we assigned a low level of certainty to the time of the match as a risk factor.

Mechanism of injury

In most studies reporting on the mechanism of injury for concussion, a collision with another player either accidentally or illegally was often the mechanism of concussion in various sports.^{45 49 98 99} However, a major limiting factor of these studies is the lack of risk estimation with often only the percentage or proportion of concussion reported. Therefore, only two prospective cohort level II studies were identified^{100 101} (see online supplementary table S1.8). One study found a significantly different concussion incidence between unintentional and intentional collisions ($p=0.04$).¹⁰⁰ Specifically, a hit to the head or helmet was a significantly common mechanism of concussion injury in ice hockey ($p=0.007$), soccer ($p<0.0001$) and

American football players ($p < 0.0001$).¹⁰¹ However, no risk estimate was measured in both studies and no measure of concussion risk could be performed.

Although collision of the head against a surface is viewed as the common mechanism of concussion injury, to our knowledge no high-quality studies have ascertained risk estimates for mechanism of sustaining a concussion. The poor data analysis and lack of risk estimation result in a low level of certainty for mechanism of injury and concussion risk.

Playing position

Playing position as a risk factor for concussion is often investigated in American football, ice hockey and rugby. Six studies, two of which are high-quality level I studies, showed no effect of playing position on concussion risk.^{23 25 74 97 102 103} An increased and decreased risk for specific playing positions was reported in two studies with a level of evidence of II and I, respectively^{21 104} (see online supplementary Table 1.9). The recalculated IRR* showed that the offensive quarterback position, in American football, had the highest risk of sustaining a concussion compared with all other playing positions. Specifically, quarterbacks had a 1.7-fold to 5-fold increase in concussion risk compared with other offensive positions (range of IRR*: 1.72, 95% CI 1.14 to 2.60 to 5.59, 95% CI 3.90 to 8.02)¹⁰⁴ with an exception when compared with the offensive wide receiver (quarterback vs wide receiver IRR*: 1.32, 95% CI 0.96 to 1.81), as well as an almost twofold and threefold increased risk compared with defensive positions (range of IRR*: 1.74, 95% CI 1.29 to 2.35 to 3.68, 95% CI 2.61 to 5.20).¹⁰⁴ In contrast, two American football studies found no effect of individual playing positions on concussion risk.^{25 102}

Ice hockey has three playing position categories; defence, forwards and goalie. One of the three ice hockey studies reported an almost threefold decreased risk of concussion in goalies compared with the defence and forward units. Conversely, no difference in concussion risk was observed when comparing goalies against the defence and forwards in the top 60% of competitive youth and professional ice hockey players.^{23 103} No risk estimation could be determined for the latter study¹⁰³ as only χ^2 values were reported without risk estimate.

Rugby league and union differ in rules and playing style but the types of playing positions are similar with two broad classifications; forwards and backs. Both rugby studies reported no effect of playing position on risk. However, few concussions were reported explaining the absence of a risk effect.^{74 97}

Owing to inconsistent findings among the reviewed studies, the certainty that playing position is a risk factor for concussion is low.

Playing level

The six articles assessing concussion risk in different playing levels, within the same age-group, displayed varied findings^{21 23 25 64 97 105} (see online supplementary table S1.10). Two prospective cohort studies (levels I and II) found concussion rates increased in descending divisions of college American football. Guskiewicz *et al*⁶⁴ found that there was a lower risk in the first division compared with the second and third divisions. Likewise, another study showed that concussion rates were lower in the first and second compared with the third division.²⁵ These authors proposed that the increased risk at lower playing levels may be due to poor quality of protective equipment, decreased skill levels or players having to play both offensive and defensive positions.⁶⁴ Conversely, a study on professional rugby league players found that increasing playing level tended to increase

concussion risk but this failed to reach significance.⁹⁷ Three studies found no difference in concussion risk between different playing levels. Stephenson *et al*¹⁰⁵ found no difference between the first team and the A-teams of professional rugby league teams. Two studies by Emery *et al*^{21 23} found no difference between ice hockey players grouped on ability.

From among the selected studies no consistency in results was found, therefore a low level of certainty was given to playing level as a risk factor for concussion. Further level I prospective cohort studies are required to improve the level of evidence.

Protective equipment

The ability of protective gear to reduce concussion risk was investigated in 13 studies (see online supplementary table S1.11). Six studies investigated the effect of mouth guards,^{33 74 106–109} five on padded headgear^{26 44 74 108 110} and three on the effect of face visors^{71 111 112} to reduce concussion risk.

Mouth guards have often been shown to be protective against orofacial injuries^{108 109 113} but their effect on concussion is less clear. Surprisingly, a trend for increased concussion risk was shown in American football players wearing mouth guards.³³ A possible explanation may be risk compensation, which occurs when protective equipment use induces an increase in risky behaviour that may negate the possible effect of protective equipment.^{114 115} Mouth guard use was found to have no significant effect on concussion risk in five of the six studies.^{74 106–109} However, a level II study showed a decrease in concussion rates after introducing customised mouth guards in 28 American football players.¹⁰⁶ There are several methodical criticisms of the study. Specifically, players were older when they used the customised mouth guards and there was an overrepresentation in concussion rates when using standard mouth guards as both match and practice injuries were included compared with only match injuries for customised mouth guards. The relation between mouth guards and concussion prevention is constrained by the use of static cadaver skulls to mimic dynamic biomechanical and biological processes¹¹⁶ the limited evidence for an association between force transduction and concussion induction¹¹⁷ and few sport concussions result from mandibular impact.¹⁰⁷

Padded headgear has been shown to decrease the risk of abrasions and lacerations, but its effectiveness in preventing concussion needs to be determined.^{118 119} In a level II retrospective cohort of adolescent soccer players, a trend for padded headgear users showed a 2.5-fold greater concussion risk.⁴⁴ This finding needs to be interpreted cautiously as no 95% CI was given and concussions were based on recall of symptoms. There is also biomechanical evidence that commercially available soccer headgear products do not have the structural ability to prevent concussions.¹²⁰ Two studies indicated that headgear had no significant effect on concussion risk in rugby union players.^{108 110} Conversely, in a large level II prospective cohort study of adult amateur rugby, the use of padded headgear was found to decrease concussion risk.²⁶ Similarly, in a level I study that included 81 concussions, headgear was found to significantly decrease concussion risk in professional rugby union teams.⁷⁴ Therefore, it seems as though large cohorts and more level I studies may be required to see an effect on concussion risk.

Two studies observed the effects of facial protection on concussions in ice hockey. No difference was found in concussion rates in players wearing full, partial or no facial protection.^{111 112} One study found that players who complained that the face mask obscured their vision were five times more likely to be concussed.⁷¹

In summary, the use of face visors showed no concussion protection and although headgear and mouth guards may play a role in concussion risk, the overall effect of protective equipment is inconclusive. Thus, a low level of certainty was given for protective equipment as a concussion risk.

Body checking

Body checking, an aggressive blocking tactic, is thought to increase injury risk, especially in junior players. Four of the six identified studies, showed a greater concussion risk due to body checking in ice hockey players (11–16 years;^{22 23 27 62 121 122} online supplementary table S1.12). A prospective study of 986 ice hockey players reported an increased concussion risk for those permitted to body check (13–14 and 15–16 years) compared with those who were not (9–10 years).⁶² However the age difference between the comparative groups confounds the effect of checking on concussion risk. Although prohibiting body checking at younger age groups are thought to increase injury risk due to poor technique.⁷² Emery *et al*²² found no difference in concussion risk between players with body-checking experience (checking allowed at 9–10 years old) and novices (no checking allowed).

Only two of the five studies on body checking were of a high level of evidence of I, whereas the remaining studies were given a level of evidence of II and III. A limitation is that most studies lacked age-matched comparative groups; thus a low level of certainty was given for body checking as a concussion risk estimate.

Environment

Three studies analysed whether environmental factors affect the risk of concussion^{36 123 124} (see online supplementary table S1.13). Two level II prospective studies compared concussion risk on natural and artificial grass in elite soccer players. Artificial surfaces are firmer and therefore increase speed of play, possibly resulting in higher impact collisions.¹²⁵ In

addition, artificial surfaces are often harder, which may increase the force of impact if the head collides with the ground.¹²⁶ Neither study found a significant difference in concussion risk between the two surfaces.^{123 124} However, Bjørneboe *et al*¹²³ noted a tendency for match concussion to be reduced on the artificial turf. Both studies, however, lacked the large numbers of concussion often required to identify significant associations.

A large-scale level II retrospective study found that youth football-related concussions were more likely to occur at school compared with at a recreational facility or at home.³⁶ Owing to the limited number and size of studies observing the effect of playing environment, a low level of certainty was assigned.

Other

Risk factors that were only assessed by a single study are discussed below^{21 27 28 46 63 83 101 127} (see online supplementary table S1.14). Rugby union players with less training and below average body mass index had higher concussion rates.⁶³ Contrastingly, junior ice hockey players in the lowest body weight quartile were at an increased concussion risk.²⁷ This may be due to the aggressive nature of ice hockey in which players use their own body weight to gain advantage resulting in heavier players often knocking down their lighter opponents. In wheelchair basketball, players who used a wheelchair as their primary form of locomotion sustained less concussions, leading to speculation that those with less severe disability and more physical ability travelled faster potentially increasing concussion risk.⁴⁶ It has been proposed that athletes with low physical fitness become fatigued earlier in the game, leading to inability to react efficiently to the dynamic game environment and increasing injury risk.²⁸ Although only trends for fewer concussions were reported in youth ice hockey winning teams²¹ and football players with low aerobic fitness²⁸ physicality may influence concussion risk.

Interestingly, a trend was identified between the temporal side of the head and concussion incidence in soccer and football players.¹⁰¹ Impacts on the side of the head are often outside of the player's field of vision limiting the ability to engage the neck muscles necessary to decrease head acceleration after impact, thus increasing concussion risk. The side of the head may also be biomechanically more vulnerable to an impact force.¹⁰¹ As a consequence of insufficient research on these potential risk factors, a low certainty was assigned to each (see online supplementary table S1.14).

Limitations

There were several limitations to this systematic review. Studies that did not differentiate between concussions and other types of mild traumatic brain injury or only included concussions where there was loss of consciousness were excluded from our analysis. A systematic review of concussion incidence in different sports has previously been published;¹²⁸ therefore sport type, as a risk factor, was excluded from the current review. Although biomechanical models are important research tools, most of the biomechanical studies used simulation models or mainly investigated head impacts and not concussion, specifically. Consequently, these studies were excluded from this systematic review.

Future research

The investigation of risk factors is an important step towards understanding the aetiology of concussion. Although several risk factors were identified in the appraised studies, poor study methodology caused constrained estimation of concussion risk

Table 3 Summary of the level of certainty of concussion risk factors

Level of certainty		
High	Moderate	Low
Previous concussion	–	Sex
Match vs practice		Age
		Genetics
		Behaviour
		Match period
		Mechanisms of injury
		Playing position
		Playing level
		Protective equipment
		Body checking
		Environment
		Anthropometry
		Fitness
		Weather season
		Performance
		Preseason symptoms
		Exposure
		Injury location
		Disability

for almost all the investigated risk factors, except previous concussion and match play. Prospective cohort design and consistent measures of risk should be employed in future studies. Specifically, the effect of body checking using age-matched comparison groups, the effect of gender in male-dominated contact sports, genetic risk factors and the effect of age all require further research. In addition, several neurological disorders such as migraines, encephalitis and epilepsy^{2 129} have been suggested to affect concussion risk but lacked sufficient research to be identified in this systematic review. Further studies are required to identify whether a possible association exists between these factors and concussion.

CONCLUSION

This evidence-based systematic review provides descriptive analysis of several risk factors for sports concussion. Specifically, athletes with a history of previous sport-related concussions were at a higher risk of sustaining another concussion which is supported by the findings of the new Zurich, 2012 consensus statement.² In addition to previous concussion, match play increased concussion risk with high certainty and therefore a good estimate of risk may be established. All other risk factors have a low certainty that it associates with risk of concussion. Finally, the devastating effect on quality of life, especially in the athlete's later years, of debilitating neurological complications such as CTE as a consequence of repetitive concussive head impacts are a concern. Consequently, more high-quality level I studies are needed to confirm factors which may modulate concussion risk to reduce concussion incidence, improve management of athletes at high risk and prevent serious health complications in the future.

What are the new findings

- ▶ To our knowledge, this is the first evidence-based systematic review of concussion risk and providing descriptive evidence of potential risk factors.
- ▶ There is a high level of certainty that previous concussion(s) and match play increases risk of sustaining subsequent concussions.
- ▶ Sex, playing position, playing level, behaviour, environment and mechanism of injury are all promising factors, but further research is required to establish if they are significant risk factors.

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