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 US annually. Identifying risk factors may assist 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.

Keywords: sports concussion, risk factor, level of evidence, level of certainty

Introduction

Approximately 1.6-3.8 million concussions reported in the US 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 hours 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 speed[5] or memory dysfunction[6].

Research suggests that concussion risk may be modulated by several factors. Studies often report sports concussion occurring more frequently in females, younger athletes and those with a history of previous concussion[7–10]. However, the exact aetiology of concussion still remains 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 papers highlight CTE as a potentially significant consequence of repeated head trauma in contact sports[4,11,12], making the prevention of concussion that 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 used 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 unrelated to the topic or met the exclusion criteria outlined in Table 1.1.

Table 1.1: 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 (e.g. fractures, lesions).
5. Studies of animal or biomechanical models of brain injury.

Two rounds of reviewing the literature, using the three-step method in each round, were performed. Round one pertained to the review of articles from the search results of the databases and round two involved reviewing the reference lists of identified articles from round one. Thereafter, the identified articles from rounds one and two were stringently appraised according to the inclusion criteria summarised in Table 1.2.

Table 1.2: 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 (e.g. odds ratio), with the 95% confidence interval (CI) and/or p-value obtained from chi-square tests, or the necessary data to calculate these measures of association.

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 that studies had not reported these measures, the IRR including 95% CI was calculated[16] 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 confidence interval was calculated and an asterisk was assigned. Notably, certain studies reporting a chi-square p-value only were included in the appraisal as it is a measure of statistical significance but is limited in interpretation and estimation of risk.

Level of evidence and certainty

Table 1.3: 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

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 1.3)[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 Force[20] and modified by Posthumus et al.[17] are detailed in Table 1.4.

Table 1.4: 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.

Results and Discussion

The article selection process is outlined in Figure 1. In total, the analyses of the 86 appraised studies identified 14 risk factors for sports concussion which are discussed below and summarised in Tables 2 and 3.

2.1 Intrinsic Risk Factors

2.1.1 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 thirteen studies reported an increased risk of concussion in those athletes with a history of previous concussion (Table 2.1.1).

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

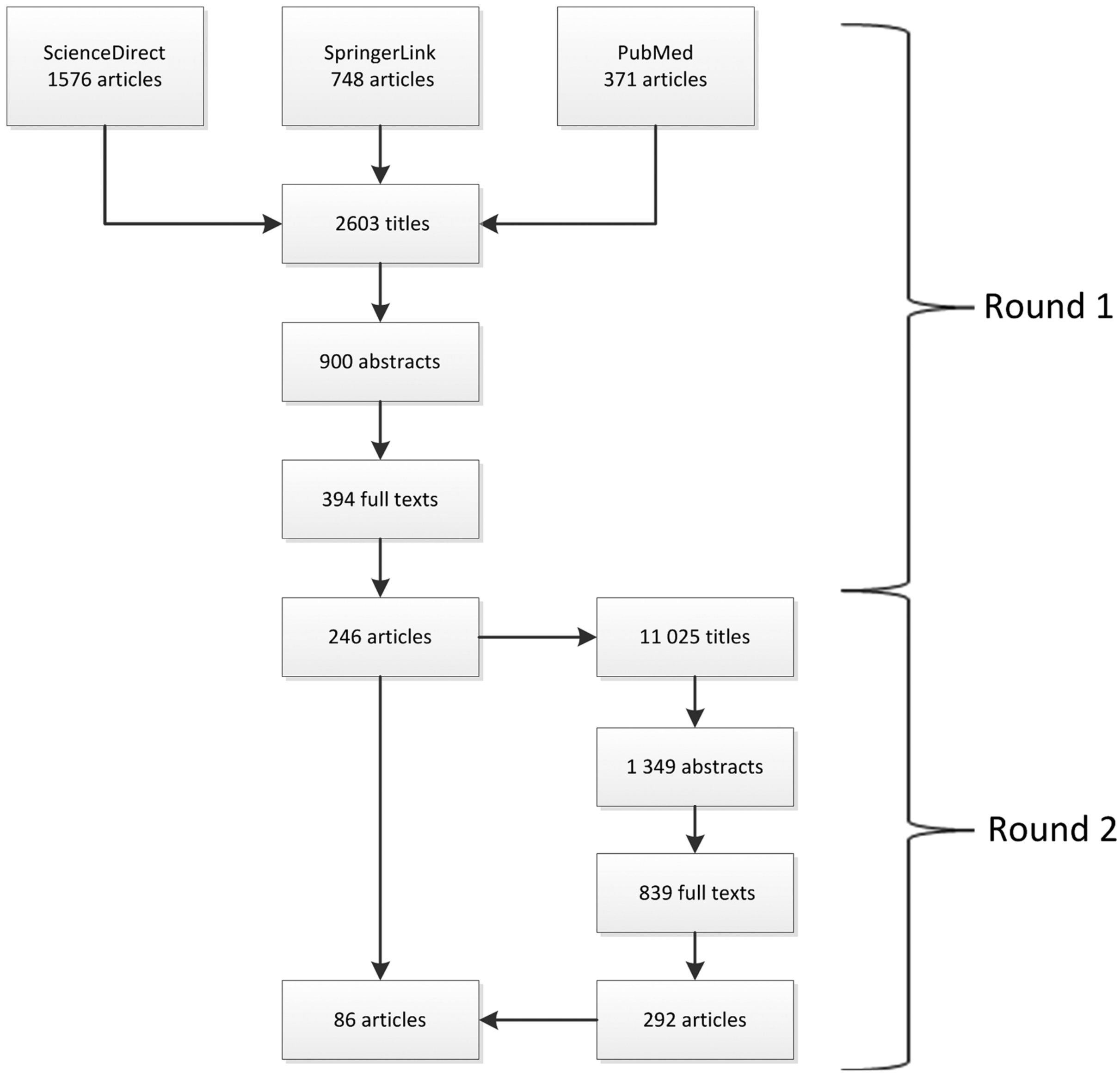

Figure 1: Outline of literature search procedure and article selection. In round one 2 603 articles were identified using the three electronic database searches. After the title, abstract and full text screening steps the number of articles was reduced to 900, 394 and 246 articles respectively. From the reference lists of the 246 full text selected articles, 11 025 articles were extracted. Using the same screening steps as round one the 11 025 articles were reduced to 1 349 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.

Three studies of American football and soccer players showed two- 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 (Table 2.1.1)[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 he published studies provide a good estimate of risk and are unlikely to be affected by future studies. Therefore, a history of previous concussion increases concussion risk with a high level of certainty.

2.1.2 Sex

Twenty-three studies investigated whether there was a difference in concussion risk between male and female athletes (Table 2.1.2). Four studies found males to be at increased risk, ten studies showed females had a greater risk of concussion, and nine studies found no association.

Males were at a greater risk in youth alpine sports[35], youth American football[36], lacrosse[37] and when comparing different sport types[38]. However, comparing different sport types, between sexes, introduces a bias as males tend to play high-collision sports with increased concussion risk. Further, males 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.

Females were found to have a 1.5 to 2.5 fold greater concussion risk in various levels of soccer[33,39–42]. Two studies found no significant difference between male and female soccer players, but included only five and 29 concussions, respectively and therefore lacked statistical power. Females had a 1.5 and three-fold higher concussion risk in the five studies on basketball populations[39,41,43–45]. Four studies compared female softball and male baseball players with three studies reporting greater risk in softball players[39,46,47]. Several possible reasons for increased concussion susceptibility in females have been proposed. Female soccer players have been found to have increased head acceleration during impacts compared to males, indicative of decreased neck strength and effective head mass[48,49]. It has been suggested that the increased head to ball ratio in female soccer players may also play a role[50]. Another reason for higher concussion rates in females may be their increased willingness to report injuries[51].

Nine studies observed no difference in concussion risk between sexes in taekwondo[52–54], soccer[55,56], collegiate rugby[57], lacrosse[39,41] and when comparing different sport types[58,59]. 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, females 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.

2.1.3 Age

Fourteen studies examined whether concussion risk was modulated by age (Table 2.1.3). Eight studies identified the older age group to be associated with greater concussion risk; conversely three studies found the younger age group at greater risk and three studies found no effect of age.

Collegiate cheerleaders were at a three-fold greater concussion risk compared to those younger than 18 years old, although only 23 concussions were recorded in 9022 participants[65]. An increased concussion risk in collegiate athletes is not exclusive to cheerleaders. A level III retrospective study, investigating over 3 700 sport concussions for several sports, found an increased likelihood of concussion occurring in 10-14 and 15-18 year olds compared to the younger cohort (5-10 years)[58]. Furthermore, significantly higher concussion rates were observed in 11-16 year old ice hockey players compared to 9-10 years[66]. However, this finding is most likely confounded by the effect of body checking only permitted in age groups above 10 years.

Contrastingly, children younger than six years old were at greater risk of concussion in roller skating, ice skating and rollerblading[67]. In a large scale level I prospective cohort study, including over 1 000 concussions, high school football players were at an increased concussion risk compared to collegiate players[68].

Three studies found no difference in concussion risk between age groups when comparing high school to adult club rugby union[69], 11/12 to 13/14 year old ice hockey players[23] and male lacrosse high school athletes[70].

Although more studies reported greater risk in the older cohort, only one of these studies was a high quality level I[43] and the remaining seven were level II or III mainly due to small number of concussions and a weaker study design (Table 2.1.3). 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.

2.1.4 Genetics

Genetic association studies on concussion risk are limited. The apolioprotein 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 (Table 2.1.4). 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[90,91]. The TT genotype of the -186bp promoter variant of the *APOE* gene was significantly associated with a history of one or more previous concussions in intercollegiate soccer and American football[92]. The two studies that observed no association between the *APOE* ε4 allele, concussion history[93] and multiple concussions[30], recorded a small number of concussions. Therefore, the absence of an association must be interpreted cautiously. As a consequence of too few studies and none with a high level of evidence of I, the genetic risk for concussion was given a low level of certainty.

2.1.5 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 (Table 2.1.5). Three studies investigated concussion risk and player behaviour in ice hockey, an aggressive collision sport[89]. Athletes who played ice hockey for tension and aggression relief were significantly more likely to sustain a concussion compared to players with less aggressive tendencies[86]. 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[21,23].

The Korean martial art of taekwondo has developed into a full contact sport involving permissible contact to the head[94]. Taekwondo athletes who used defensive blocking skills during a competition showed a significantly decreased concussion risk[54].

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

2.2 Extrinsic Risk Factors

2.2.1 Match vs. Practice

All of the 29 studies indicated that there was a higher risk of concussion in matches compared to practices (Table 2.2.1). The increased risk of high impact collisions in match play compared to practices, is the primary reason for the increased risk[34]. 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.

2.2.2 Match period

Two studies examined the period of the match as a potential risk factor for concussion (Table 2.2.2). The first study found there were significantly more concussions in the second compared to the third period in elite ice hockey games[103]. The second study in found no difference in concussion rates between the first and second halves of professional rugby league football[64]. Due to the limited number of studies we assign a low level of certainty to the time of the match as a risk factor.

2.2.3 Mechanism of injury

In most studies reporting on the mechanism of injury for concussion, a collision with another player either accidently or illegally was often the mechanism of concussion in various sports[42,56,95,96]. 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 (Table 2.2.3)[97,98]. One study found a significantly different concussion incidence between unintentional and intentional collisions ($p=0.04$)[97]. 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 ($p<0.0001$)[98]. 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 results in a low certainty level for mechanism of injury and concussion risk.

2.2.4 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. An increased and decreased risk for specific playing positions was reported in two studies with a level of evidence of II and I, respectively (Table 2.2.4). The recalculated IRR* showed that the offensive quarterback position, in American football, had the highest risk of sustaining a concussion compared to all other playing positions. Specifically, quarterbacks had a 1.7- to five-fold increase in concussion risk compared to other offensive positions (range of IRR*: 1.72, 95% CI 1.14 - 2.60 to 5.59, 95% CI 3.90 - 8.02)[60], with an exception when compared to the offensive wide receiver (quarterback vs. wide receiver IRR*: 1.32, 95% CI 0.96 - 1.81), as well as an almost two- and three-fold increased risk compared to defensive positions (range of IRR*: 1.74, 95% CI 1.29 - 2.35 to 3.68, 95% CI 2.61 - 5.20)[60]. In contrast, two American football studies found no effect of individual playing positions on concussion risk[29,61].

Ice hockey has three playing position categories; defence, forwards and goalie. One of the three ice hockey studies reported an almost three-fold decreased risk of concussion in goalies compared to 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[21,62]. No risk estimation could be determined for the latter study[62] as only chi-squared 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[63,64].

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

2.2.5 Playing level

The six articles assessing concussion risk in different playing levels, within the same age-group, displayed varied findings (Table 2.2.5). Two prospective cohort studies (level I and II) found concussion rates increased in descending divisions of college American football. Guskiewicz et al. [68] found that there was a lower risk in the 1st division compared to the 2nd and 3rd divisions. Likewise, another study showed concussion rates were lower in the 1st and 2nd compared to the 3rd division[29]. 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[68]. Conversely, a study on professional rugby league players found increasing playing level tended to increased concussion risk but this failed to reach significance[64]. Three studies found no difference in concussion risk between different playing levels. Stephenson et al. [87] found no difference between the 1st team and the A-teams of professional rugby league teams. Two studies by Emery et al. [21,22] found no difference between ice hockey players grouped on ability.

From 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.

2.2.6 Protective equipment

The ability of protective gear to reduce concussion risk was investigated in 13 studies (Table 2.2.6). Six studies investigated the effect of mouth guards, five on padded headgear and three on the effect of face visors to reduce concussions risk.

Mouth guards have often been shown to be protective against orofacial injuries[71–73], 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[74,75]. Mouth guard use was found to have no significant effect on concussion risk in five of the six studies[63,71,72,76,77]. However, a level II study showed concussion rates decrease after introducing customised mouth guards in 28 American football players[76]. 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 to 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 processes[78], the limited evidence for an association between force transduction and concussion induction[79] and few sport concussions result from mandibular impact[77].

Padded headgear has been shown to decrease the risk of abrasions and lacerations, but its effectiveness in preventing concussion needs to be determined[80,81]. In a level II retrospective cohort of adolescent soccer players, a trend for padded headgear users showed a 2.5-fold greater concussion risk[40]. 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 head gear products do not have the structural ability to prevent concussions[82]. Two studies indicated that head gear had no significant effect on concussion risk in rugby union players[72,83]. Conversely, in a large level II prospective cohort study of adult amateur rugby, the use of padded headgear was found to decrease concussion risk[25]. Similarly, in a level I study that included 81 concussions, headgear was found to significantly decrease concussion risk in professional rugby union teams[63]. 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[84,85]. One study found that players who complained that the face mask obscured their vision were five times more likely to be concussed[86].

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.

2.2.7 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) (Table 2.2.7)[21,24,88]. 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 to those who were not (9-10 years). However, the age difference between the comparative groups confounds the effect of checking on concussion risk[66]. Although prohibiting body checking at younger age groups are thought to increase injury risk due to poor technique[89], Emery et al. [23] 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.

2.2.8 Environment

Three studies observed whether environmental factors affect the risk of concussion (Table 2.2.83). 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[99]. In addition, artificial surfaces are often harder, which may increase the force of impact if the head collides with the ground[100]. Neither study found a significant difference in concussion risk between the two surfaces[101,102]. However, Bjornboe et al.[101] 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 to at a recreational facility or at home[36]. Due to the limited number and size of studies observing the effect of playing environment, a low level of certainty was assigned.

2.3 Other

Several miscellaneous risk factors were examined (Table 2.3). Rugby union players with less training and above average body mass index had higher concussion rates[104]. Contrastingly, junior ice hockey players in the lowest body weight quartile were at an increased concussion risk[24]. 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 that 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[45]. 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 teams[22] and football players with low aerobic fitness[28], 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[98]. 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[98]. As a consequence of insufficient research on these potential risk factors, a low certainty was assigned to each (Table 2.3).

Table 2: Research studies appraised for risk factors of sports concussion

Risk factor	Article	Study design	Population (cohorts compared)	Number of concussions	Results	Level of evidence	Level of certainty
Intrinsic Risk Factors							
2.1 Previous concussion	**Increased risk**						**High**
	Emery et al. 2010 [21]	PC	Youth ice hockey players	101	IRR: 2.14 (95% CI 1.28 – 3.55)	**I**	
	Emery et al. 2011 [22]	PC	Youth ice hockey players	183	IRR: 2.04 (95% CI 1.46 – 2.86) p<0.001	**I**	
	Zemper 2003 [27]	PC	High school & college American football players	572	College RR: 5.30 (95% CI 4.3 – 6.6) High school RR: 6.60 (95% CI 5.0 – 8.8)	**I**	
	Guskiewicz et al. 2003 [29]	PC	Collegiate American football players	196	Two previous concussions IRR: 2.50 (95% CI 1.5 - 4.1) >three previous concussions IRR: 3 (95% CI 1.6 - 5.6)	**I**	
	Hollis et al. 2009 [25]	PC	Amateur rugby union players	347	one previous concussion IRR: 1.75 (95% CI 1.11 - 2.76) p=0.016 > two previous concussions IRR: 1.65 (95% CI 1.11 - 2.45) p=0.013	**II**	
	Schneider et al. 2013 [24]	PC	Youth ice hockey players	175	IRR: 2.06 (95% CI 1.52 – 2.80)	**II**	
	Kontos et al.	PC	High school	23	OR: 3.71 (95% CI	**II**	

	2005 [28]		American football players		1.36 - 10.18)		
	Emery et al. 2011 [23]	PC	Youth ice hockey players	51	IRR: 1.87 (95% CI 1.19 - 2.94)	**II**	
	Zemper 1994 [26]	PC	Collegiate American football players	245	IRR*: 5.95 (95% CI 4.38 - 8.09)	**II**	
	Kristman et al. 2008 [30]	PC	Collegiate athletes†	28	> one previous concussion RR: 3.4 (95% CI 1.4 – 8.4)	**II**	
	No effect on risk						
	Delaney et al. 2000 [32]	RC	Elite American football players	69	OR: 5.20, p<0.0001	**II**	
	Delaney et al. 2001 [31]	RC	College soccer & American football players	39	Soccer OR: 11.10, p<0.05 American football OR: 3.80, p<0.05	**II**	
	Delaney et al. 2002 [33]	RCS	College soccer & American football players	40	American football OR: 1.94, p<0.05 Soccer OR: 3.15, p<0.05	**III**	
[2.3 Sex]()	**Males showed increased risk**						**Low**
	Hinton et al. 2005 [37]	PC	High school lacrosse players	75	IRR: 2.99 (95% CI 1.65 - 5.79)	**I**	
	Bridges et al. 2003 [35]	PCS	Alpine sports participants	147	OR: 1.61 (95% CI 1.09 - 2.37)	**II**	
	Nation et al. 2011 [36]	RC	Youth American football players	4468	OR: 1.76 (95% CI 1.37 - 2.25)	**II**	
	Emery et al. 2009 [38]	RC	Junior high school athletes†	n/a	OR: 2.08 (95% CI 1.16 - 3.85)	**II**	
	Females showed increased risk						

Lincoln et al. 2011 [39]	PC	High school soccer, basketball, softball & baseball players	2651	Basketball IRR: 1.70 (95% CI 1.3 - 2.2) soccer IRR: 2.1 (1.6 - 2.6) Baseball/softball IRR: 1.90 (95% CI 1.2 - 3.0)	**I**
Gessel et al. 2007 [43]	PC	Youth basketball & soccer football players	878	Soccer IRR: 1.68 (95% CI 1.08 - 2.60) p=0.03, Basketball IRR: 2.93 (95% CI 1.64 - 5.24) p<0.01	**I**
Castile et al. 2012 [46]	RC	High school athletes[†]	2402	Soccer IRR*: 1.5 (95% CI 1.2 - 1.8) Basketball IRR*: 1.96 (95% CI 1.5 - 2.5) Baseball/softball IRR*: 2.68 (95% CI 1.75 - 4.1)	**II**
Marar et al. 2012 [112]	RC	Male & female high school athletes[†]	1936	Soccer IRR: 1.79 (95% CI 1.40 – 2.29) Baseball/softball IRR: 3.2 (95% CI 1.97 – 5.19)	**II**
Deitch et al. 2006 [44]	RC	Male & female professional basketball players	51	IRR*: 3.00 (95% CI 1.5 - 6.0)	**II**
Covassin et al. 2003 [41]	RC	Collegiate athletes[†]	304	Basketball IRR*: 1.52 (95% CI 1.06 - 2.19) Soccer IRR*: 1.58 (95% CI 1.23 -	**II**

				2.03) Baseball/softball IRR*: 1.10 (95% CI 0.74 - 1.6) Lacrosse IRR*: 0.73 (95% CI 0.46 - 1.18)	
Delaney et al. 2008 [40]	RC	Adolescent soccer players	133	RR: 1.97, p<0.0001	**II**
Fuller et al. 2005 [42]	RCS	Professional soccer players	28	IRR*: 2.38 (95% CI 1.12 – 5.00)	**II**
Delaney et al. 2002 [33]	RC	Collegiate soccer players	40	OR: 2.60, p < 0.005	**II**
Wessels et al. 2012 [45]	RC	Wheelchair basketball players	102	OR: 2.64, p=0.002	**II**
No effect on risk					
Pieter & Zemper 1999 [53]	PC	Youth taekwondo athletes	63	IRR*: 1.12 (95% CI 0.59 - 2.1)	**I**
Kerr et al. 2008 [57]	PC	Collegiate rugby players	65	IRR*: 1.36 (95% CI 0.83 - 2.25)	**I**
Boden et al. 1998 [56]	PC	Collegiate soccer players	29	IRR*: 0.66 (95% CI 0.32 – 1.39)	**II**
Koh et al. 2004 [54]	PC	Youth taekwondo athletes	229	Middle school IRR*: 1.14 (95% CI 0.65 - 2.0) High school IRR*: 0.99 (95% CI 0.71 - 1.38)	**II**
Zemper & Pieter 1989 [52]	PC	Elite taekwondo athletes	2	IRR*: 1.04 (95% CI 0.06 - 16.7)	**II**
Yang et al. 2008 [58]	RC	Youth athletes[†]	755	OR: 1.14 (95% CI 0.87 - 1.49)	**II**

	Emery et al. 2005 [55]	PC	Adolescent soccer players	5	IRR*: 1.48 (95% CI 0.25 - 8.88)	**II**	
	Emery et al. 2006 [59]	RC	High school athletes[†]	202	OR: 0.79 (95% CI 0.58 - 1.06)	**II**	
	Lincoln et al. 2007 [70]	RC	High school & collegiate lacrosse players	351	High school IRR: 0.72 (95% CI 0.52 - 1.12) Collegiate IRR:0.86 (95% CI 0.65 - 1.13)	**II**	
2.5 Age	**Younger cohort showed increased risk**						**Low**
	Guskiewicz et al. 2000 [68]	PC	Youth American football players (High school vs. college players)	1003	IRR*: 1.78 (95% CI 1.57 - 2.02)	**I**	
	Koh et al. 2004 [54]	PC	Taekwondo athletes (Middle vs. high school; 11-19 years)	229	OR: 1.89 (95% CI 1.36 – 2.63)	**II**	
	Knox et al, 2006 [67]	RC	Youth ice skaters (<six vs. >six years)	15 985	RR: 1.21 (95% CI 1.15 – 1.27) p<0.001	**II**	
	Older cohort showed increased risk						
	Gessel et al. 2007 [43]	PC	Youth athletes[†] (College vs. high school)	878	RR: 1.86 (95% CI 1.63 - 2.12) p<0.01	**I**	
	Nation et al. 2011 [36]	RC	Youth American football players (12-17 vs. 6-11 years)	4468	OR: 1.93 (95% CI 1.74 - 2.15)	**II**	
	Leininger et al. 2007 [126]	RC	Youth soccer players (15-18 vs. <15 years)	830	RR: 1.46 (95% CI 1.09 - 7.97) p<0.01	**II**	

	Shields & Smith 2009 [65]	PC	Amateur cheerleaders (Collegiate vs. younger athletes)	23	RR: 2.98 (95% CI 1.34 - 6.59) p=0.01	**II**	
	Emery et al. 2006 [66]	PC	Youth ice hockey players (9/10 vs. 13/14 & 15/16 years)	54	13/14 vs. 9/10 years RR: 4.04 (95% CI 1.17 - 21.54) 15/16 vs. 9/10 years RR: 3.41 (95% CI 1.02 - 17.87)	**II**	
	Hollis et al. 2011 [104]	PC	Community rugby union players (Adult players vs. high school)	215	HR*: 1.64 (95% CI 1.03 – 2.56)	**II**	
	Lincoln et al. 2007 [70]	RC	Youth lacrosse players (College vs. high school)	351	Female IRR*: 1.52 (95% CI 1.08 - 2.17)	**II**	
	Yang et al. 2008 [58]	RCC	Youth athletes[†] (10 -14 & 15-18 vs. 5-10 years)	3712	10-14 vs. 5-10 years OR: 2.28 (95% CI 1.64 - 3.18) 15-18 vs. 5-10 years OR: 1.91 (95% CI 1.34 - 2.71)	**III**	
	No effect on risk						
	Emery et al. 2011 [23]	PC	Youth ice hockey players (11-12 vs. 13-14 years)	100	IRR: 0.87 (95% CI 0.51 - 1.50)	**I**	
	Lee & Garraway, 1996 [69]	PC	High school & club rugby players (High school vs. adult players)	38	IRR*: 0.62 (95% CI 0.33 - 1.17)	**II**	

	Lincoln et al. 2007 [70]	RC	Youth lacrosse players (High school vs. college players)	351	Male IRR*: 0.76 (95% CI 0.57 - 1.01)	**II**	
[2.9 Genetics]()	**Increased risk**						**Low**
	Terrell et al. 2008 [92]	RC	Intercollegiate soccer & American football players (TT *APOE* genotype & concussion history)	90	OR: 2.70 (95% CI 1.1 - 6.8) p=0.03	**III**	
	No effect on risk						
	Kristman et al. 2008 [30]	PC	Collegiate athletes[†] (*APOE* ε4 allele vs. concussion history)	28	Adjusted HR: 1.06 (95% CI 0.41 – 2.72), RR: 1.20 (95% CI 0.5 - 2.6)	**II**	
	Tierney et al. 2010 [93]	RC	Collegiate female soccer & male American football players (rare *APOE* allele vs. concussion history, minor APOE allele carriers vs. sustaining >two concussions)	57	Rare *APOE* allele OR: 9.80 (95% CI 1.00 - 96.55) p=0.05, Minor APOE allele OR: 8.40 (95% CI 1.03 - 68.79) p=0.04	**II**	
[2.10 Behaviour]()	**Increased risk**						**Low**
	Gerberich et al. 1987 [86]	RC	High school ice hockey players (aggression & tension relief)	249	OR: 4.20 (99% CI 1.68 - 10.32) p<0.002	**II**	
	Decreased risk						
	Koh et al. 2004 [54]	PC	Youth taekwando athletes (using blocking skills)	229	OR: 0.57 (95% CI 0.37 – 0.88) p=0.01	**I**	

	No effect on risk						
	Emery et al. 2010 [21]	PC	Youth ice hockey players (preference to body check)	101	IRR: 2.52 (95% CI 1.00 - 6.35)	**I**	
	Emery et al. 2011 [23]	PC	Youth ice hockey players (with body checking experience vs. no experience)	51	IRR: 0.87 (95% CI 0.51 - 1.50)	**II**	
Extrinsic Risk Factors							
2.2 Match vs. practice	**Increased risk**						**High**
	Kemp et al. 2008 [63]	PC	Male professional rugby players	101	IRR*: 205 (95% CI 83.4 - 503.8)	**I**	
	Gessel et al. 2007 [43]	PC	Youth athletes†	878	IRR*: 4.80 (95% CI 3.9 - 5.9)	**I**	
	Nilsson et al. 2013 [105]	PC	Male professional soccer players	48	RR: 78.5 (95% CI: 24.4 - 252.5)	**I**	
	Castile et al. 2012 [46]	RC	High school athletes†	2402	Football IRR*: 8.13 (95% CI 7.29 – 9.01) Boys soccer IRR*: 11.68 (95% CI 7.9 - 17.3) Girls soccer IRR*: 13.8 (95% CI 9.6 - 19.7) Volleyball IRR*: 2.4 (95% CI 1.4 – 4.1) Boys basketball IRR*: 5.2 (95% CI 3.5 - 7.8) Girls basketball IRR*: 7.8 (95% CI	**II**	

				5.5 - 11) Wrestling IRR*: 3.3 (95% CI 2.4 - 4.6) Baseball IRR*: 5.5 (95% CI2.5 - 12.2) Softball IRR*: 2 (95% CI 1.2 - 3.2)	
Kuzuhara et al. 2009 [106]	PC	Elite ice hockey players	5	IRR: 16.00 (95% CI 1.8 - 143.2)	**II**
Agel et al. 2007 [107]	RC	Female collegiate ice hockey players	77	IRR: 8.20 (95% CI 5.0 - 13.5)	**II**
Agel et al. 2007 [108]	RC	Female collegiate basketball players	240	IRR: 3.30 (95% CI 2.8 - 4.0)	**II**
Dick et al. 2007 [109]	RC	Female collegiate field hockey players	129	IRR: 6.10 (95% CI 4.3 - 8.7)	**II**
Dick, et al. 2007 [110]	RC	Female collegiate lacrosse players	213	IRR: 4.60 (95% CI 3.5 - 6.0)	**II**
Dick et al. 2007 [111]	RC	Male collegiate basketball players	387	IRR: 2.70 (95% CI 2.6 - 2.8)	**II**
Marar et al. 2012[112]	RC	Male & female high school athletes†	1936	Male football IRR: 7.4 (95% CI 6.5 - 8.4) Male ice hockey IRR: 13.2 (95% CI 7.0 – 25.0) Male lacrosse IRR: 9.5 (95% CI 5.5 – 15.5) Male soccer IRR: 13.5 (95% CI 7.8 – 23.3) Male wrestling IRR: 3.6 (95% CI 2.5 – 5.2)	**II**

				Male basketball IRR: 6.8 (95% CI 4.3 – 10.7) Male baseball IRR: 11.0 (95% CI 3.0 – 26.1) Female soccer IRR: 11.6 (95% CI 7.6 – 17.6) Female lacrosse IRR: 6.6 (95% CI 3.8 – 12.1) Female basketball IRR: 9.2 (95% CI 5.5 – 14.1) Female field hockey IRR: 2.9 (95% CI 1.7 – 5.1) Female softball IRR: 3.2 (95% CI 1.9 – 5.4) Female volleyball IRR: 2.1 (95% CI 1.04 – 4.3)	
Dick et al. 2007 [34]	RC	Male collegiate football players	4404	IRR 11.10 (95% CI 10.5 - 11.8)	**II**
Agel et al. 2007 [113]	RC	Male collegiate soccer players	500	IRR: 13.50 (95% CI 10.9 - 16.6)	**II**
Agel et al. 2007 [114]	RC	Male collegiate ice hockey players	527	IRR: 14.70 (95% CI 11.9 - 18.2)	**II**
Dick et al. 2007 [115]	RC	Male collegiate lacrosse players	271	IRR: 9.00 (95% CI 7.1 - 11.5)	**II**
Dick et al. 2007 [116]	RC	Female collegiate soccer players	593	IRR: 11.80 (95% CI 11.4 - 12.3)	**II**

Marshall et al. 2007 [117]	RC	Female collegiate softball players	228	IRR: 3.60 (95% CI 3.4 - 3.8)	**II**
Booher et al. 2003 [118]	PC	Male collegiate football players	373	IRR*: 22.20 (95% CI 17.9 - 27.7)	**II**
Goodman et al. 2001 [119]	PC & RC	Male amateur ice hockey players	379	IRR*: 9.90 (95% CI 2.35 - 41.7)	**II**
Marshall et al. 2001 [120]	PC	Male high school rugby players	17	IRR*: 7.40 (95% CI 2.6 - 21.0)	**II**
Dick et al. 2007 [121]	RC	Male collegiate baseball players	210	IRR*: 6.30 (95% CI 4.7 - 8.5)	**II**
Agel et al. 2007 [122]	RC	Female collegiate volleyball players	141	IRR*: 2.50 (95% CI 1.8 - 3.5)	**II**
Marshall et al. 2007 [123]	RC	Female collegiate gymnasts	64	IRR*: 2.80 (95% CI 1.6 - 5.3)	**II**
Kerr et al. 2008 [57]	PC	Male & female rugby players	81	Male IRR*: 5.80 (95% CI 2.8 - 12) Female IRR*: 5.3 (95% CI 2.3 - 12.1)	**II**
Gabett et al. 2004 [124]	PC	Rugby league players	37	IRR*: 166 (95% CI 15.9 - 846)	**II**
Kristman et al. 2008 [30]	PC	Collegiate athletes[†]	28	RR: 4.10 (95% CI 1.9 - 8.8)	**II**
Guskiewicz et al. 2003 [29]	PC	Collegiate American football players	196	IRR*: 8.10 (95% CI 6.13 - 10.7)	**II**
Covassin et al. 2003 [125]	RC	Collegiate athletes[†]	1278	Male hockey IRR*: 13.5 (95% CI 8.83 – 10.67), Male soccer IRR*: 18.86 (95% CI 11.89 – 29.9), Male football: IRR*: 10.9 (95% CI 9.71 – 12.25), Male lacrosse IRR*: 10.33 (95%	**II**

					CI 6.55 – 16.29), Male wrestling IRR*: 5.14 (95% CI 3.17 – 8.33), Male baseball IRR*: 4.95 (95% CI 3.13 – 7.82), Male basketball IRR*: 43.8 (95% CI 30.38 – 63.19), Female soccer IRR*: 16.44 (95% CI 11.35 – 23.81), Female basketball IRR*: 3.52 (95% CI 2.55 – 4.86), Female lacrosse IRR*: 4.94 (95% CI 2.80 – 8.72), Female field hockey IRR*: 3.79 (95% CI 1.70 – 8.44), Female softball IRR*: 2.59 (95% CI 1.65 – 4.08), Female volleyball IRR*: 2.66 (95% CI 1.25 – 5.69)		
	Covassin et al. 2003 [41]	RC	Collegiate football, lacrosse & basketball players	558	Soccer IRR*: 16.40 (95% CI 11.4 - 23.8) Basketball IRR*: 3.52 (95% CI 2.55 - 4.86) Lacrosse IRR*:	**II**	

					4.94 (95% CI 2.8 - 8.7) Softball IRR*: 2.61 (95% CI 1.66 - 4.11) Gymnastics IRR*: 1.02 (95% CI 0.12 - 8.7)		
[2.13 Match period](#)	**No effect on risk**						**Low**
	Tegner & Lorentzon, 1996 [103]	PC & RC	Elite ice hockey players (2nd vs. 3rd period)	94	X^2: 9.71, df = 2, p<0.01	**II**	
	Hinton-Bayre et al. 2004 [64]	PC	Professional rugby league players (1st vs. 2nd half)	43	IRR: 1.26 (95% CI 0.66 - 2.44)	**II**	
[2.11 Mechanism of injury](#)	**No effect on risk**						**Low**
	Darling et al. 2011 [97]	PC	Youth hockey players (unintentional vs. intentional collisions)	29	p=0.04	**II**	
	Delaney et al. 2006 [98]	PC	Collegiate soccer, ice hockey & American football players (hit on head or helmet)	69	Soccer: p<0.0001, Football: p<0.0001, Ice hockey: p=0.0067	**II**	
[2.4 Playing position](#)	**Increased risk**						**Low**
	Pellman et al. 2004 [60]	PC	Elite American football players (quarterbacks vs. all other positions)	787	IRR*: 1.72 (95% CI 1.14 – 2.60) to 54 (95% CI 7.49-389.45)	**II**	
	Decreased risk						

	Emery et al. 2011 [22]	PC	Youth ice hockey (goalies vs. defence & forwards)	183	IRR: 0.37 (95% CI 0.17 – 0.80) p<0.001	**I**	
	No effect on risk						
	Pellman et al. 2004 [61]	PC	Professional American football players (quarterbacks, tight ends & linebackers)	887	Quarterbacks OR: 1.92 (95% CI 0.99 – 3.74) p<0.1, Tight ends OR: 1.24 (95% CI 0.58 – 2.64) Linebackers OR: 1.22 (95% CI 0.63 – 2.38) Offensive line OR: 0.54 (95% CI 0.27 - 1.08)	**I**	
	Emery et al. 2010 [21]	PC	Youth ice hockey (goalies vs. defence & forwards)	101	IRR: 0.51 (95% CI 0.16 – 1.64)	**I**	
	Wennberg et al. 2008 [62]	RC	Professional ice hockey (forwards vs. goalies)	688	X^2: 101.28, df=2, p<0.0001	**II**	
	Guskiewicz et al. 2003 [29]	RC	Collegiate American football players (all positions)	196	IRR*: 0.55 (95% CI 0.30 - 1.01) to 1.83 (95% CI 0.99 - 3.39)	**II**	
	Kemp et al. 2008 [63]	RC	Professional rugby union players (forwards vs. backs)	96	IRR*: 0.71 (95% CI 0.47 - 1.06)	**II**	
	Hinton-Bayre et al. 2004 [64]	PC	Professional rugby league players (offensive vs. defensive,	43	Offensive IRR: 1.50 (95% CI 0.76 - 3.02) forwards IRR: 1.11	**II**	

			forwards vs. backs)		(95% CI 0.58 - 2.12)		
2.7 Playing level	**Lower playing level associated with increased risk**						**Low**
	Guskiewicz et al. 2000 [68]	PC	High school & collegiate American football players (College division I,II, III)	1003	Division I vs. division II IRR*: 1.41 (95% CI 1.15 – 1.72) Division I vs. division III IRR*: 1.39 (95% CI 1.15 – 1.67) Division I vs. division III χ^2: 12.16, df = 3, $p<0.05$	**I**	
	Guskiewicz et al. 2003 [29]	PC	Collegiate American football players (College division I,II, III)	196	Division I vs. division III IRR*: 2.13 (95% CI 1.47 – 3.03) Division II vs. division III IRR*: 2.13 (95% CI 1.28 – 3.45)	**II**	
	No effect on risk						
	Emery et al. 2010 [21]	PC	Youth ice hockey players (top 20% vs. mid 40%)	101	IRR: 1.28 (95% CI 0.75 - 2.17)	**I**	
	Emery et al. 2011 [22]	PC	Youth ice hockey players (top 10% vs. next 20%)	183	IRR: 0.97 (95% CI 0.66 - 1.43) $p>0.05$	**I**	
	Stephneson et al. 1996 [87]	PC	Rugby league players (1st team vs. A-team)	35	IRR*: 0.89 (95% CI 0.46 - 1.7)	**II**	

	Hinton-Bayre et al. 2004 [64]	PC	Professional rugby league players (First team vs. age group)	43	IRR: 1.67 (95% CI 0.68 - 4.32)	**II**	
2.6 Protective equipment	**Increased risk**						**Low**
	Gerberich, 1987 [86]	RC	High school ice hockey players (perceived face mask blocked vision vs. no perception)	23	OR: 5.15 (95% CI 2.25 - 11.81) p<0.001	**II**	
	Decreased risk						
	Kemp et al. 2008 [63]	PC	Male professional rugby union players (headgear vs. no headgear)	81	IRR*: 0.43 (95% CI 0.2 - 0.94)	**I**	
	Hollis et al. 2009 [25]	PC	Amateur rugby union players (headgear vs. no headgear)	347	IRR: 0.57 (95% CI 0.40 - 0.82) p<0.01	**II**	
	Singh et al. 2009 [76]	RC	High school American football players (mouth guard users vs. non-users)	26	OR: 0.03 (95% CI 0.01 – 0.12) p < 0.05	**II**	
	No effect on risk						
	Wisniewski et al. 2004 [77]	PC	American football players (custom-made vs. non custom-made mouth guards)	369	RR: 1.32 (95% CI 0.99 - 1.75)	**I**	
	McIntosh et al. 2009 [83]	RCT	Youth rugby union players (headgear vs. no headgear)	199	Modified headgear IRR: 1.13 (95% CI 0.67 - 1.90) p= 0.65	**I**	

				Standard headgear IRR: 0.95 (95% CI 0.54 - 1.69) p=0.87	
Kemp et al. 2008 [63]	PC	Male professional rugby union players (mouth guards vs. no mouth guards)	81	IRR*: 0.69 (95% CI 0.41 - 1.17)	**I**
Delaney et al. 2008 [40]	RC	Youth soccer players (no headgear vs. headgear)	133	Adjusted RR: 2.65 (p<0.0001)	**II**
Benson et al. 1999 [84]	PC	Collegiate hockey players (half vs. full visor shields)	79	RR: 0.97 (95% CI 0.61 - 1.54) p=0.90	**II**
Marshall et al. 2005 [72]	PC	Rugby union players (Headgear/mouth guard users vs. non-users)	22	Headgear adjusted IRR: 1.13 (95% CI: 0.40 - 3.16) Mouth guard adjusted IRR: 1.62 (95% CI: 0.51 - 5.11)	**II**
Stuart et al. 2002 [85]	PC	Elite & amateur ice hockey players (full vs. half vs. no facial protection)	11	Full vs. none IRR*: 0.24 (95% CI 0.04 - 1.3) Full vs. partial IRR*: 0.35 (95% CI 0.07 - 1.82) Partial vs. none IRR*: 0.67 (95% CI 0.18 - 2.5)	**II**
Labella et al. 2002 [71]	PC	Collegiate basketball players (mouth guard	37	IRR*: 0.64 (95% CI 0.2 - 2.1)	**II**

			users vs. non-users)				
	Delaney et al. 2002 [33]	RC	Collegiate football & American football players (mouth guard users vs. non users)	40	OR: 2.46, p=0.373	**II**	
[**2.8 Body checking**]()	**Body checking increased risk**						**Low**
	Emery et al. 2010 [21]	PC	Ice hockey players (11-12 years)	101	IRR: 3.75 (95% CI 2.02 - 6.98)	**I**	
	Emery et al. 2006 [66]	PC	Community ice hockey players (13-16 years)	54	13-14 years RR: 4.04 (95% CI 1.17 - 21.54) 15-16 years RR: 3.41 (95% CI 1.02 - 17.87)	**I**	
	Schneider et al. 2013 [24]	PC	Youth ice hockey players	175	IRR: 2.69 (95% CI 1.49 – 4.84)	**II**	
	Hagel et al. 2006 [88]	RCC	Youth ice hockey players	26	IRR: 3.40 (95% CI 1.4 – 8.4)	**III**	
	No effect on risk						
	Emery et al. 2011 [23]	PC	Youth ice hockey players	51	IRR: 0.87 (95% CI 0.51 - 1.50)	**II**	
	Macpherson et al. 2006 [127]	RCC	Youth ice hockey players	62	12-13 years OR: 1.42 (95% CI 0.98 – 2.05), 13-14years OR: 1.60 (95% CI 0.68 – 3.81)	**III**	

2.12 Environment	**Increased risk**						**Low**
	Nation et al. 2011 [36]	RC	American football players (school vs. other locations)	4469	OR: 1.41 (95% CI 1.24 - 1.61)	**II**	
	No effect on risk						
	Bjørneboe et al. 2010 [101]	PC	Professional soccer players (grass vs. artificial turf)	54	IRR: 0.46 (95% CI 0.18 - 1.16)	**II**	
	Ekstrand et al. 2011 [102]	PC	Elite soccer players (grass vs. artificial turf)	37	Men RR: 0.71 (95% CI 0.29 – 1.74) p>0.05, Women RR: 0.90 (95% CI 0.20 - 4.02) p>0.05	**II**	
2.14 Other							
Anthropometry	**Increased risk**						**Low**
	Hollis et al. 2011 [104]	PC	Community rugby union players (low BMI)	215	BMI HR: 1.77 (95% CI 1.30 - 2.42)	**II**	
	Schneider et al. 2013 [24]	PC	Youth ice hockey players	175	Lower 25% weight IRR*: 1.45 (95% CI 1.05 – 2.00)	**II**	
Preseason Symptoms	Schneider et al. 2013 [24]	PC	Youth ice hockey players	175	Headache IRR: 1.47 (95% CI 1.01 – 2.13) Neck pain IRR: 1.67 (95% CI 1.15 – 2.41) Dizziness IRR: 3.11 (95% CI 1.33 – 7.26)	**II**	**Low**
Exposure	Schneider et al. 2013 [24]	PC	Youth ice hockey players	175	2 year exposure IRR: 1.37 (95% CI 1.02 – 1.86)	**II**	**Low**

Fitness	Hollis et al. 2011 [104]	PC	Community rugby union players (less training)	215	Training HR: 1.48 (95% CI 1.06 - 2.08)	**II**	**Low**
Weather season	**Decreased risk**						**Low**
	Dick et al. 2007 [34]	RC	Male collegiate football players (Spring practice rule change)	4404	IRR: 0.57 (95%CI 0.48 - 0.67)	**II**	
Performance	**No effect on risk**						**Low**
	Emery et al. 2011 [22]	PC	Youth ice hockey players (greater win-loss record)	183	Win-loss record IRR: 0.70 (95% CI 0.49 - 1.01) p>0.05 Penalty minutes IRR: 1.07 (95% CI 0.71 - 1.61)	**I**	
Fitness	Kontos et al. 2005 [28]	PC	High school American football players (low aerobic fitness vs. higher aerobic fitness)	23	OR: 1.80 (95% CI 0.68 - 4.80)	**II**	**Low**
Disability	Wessels et al. 2012 [45]	RC	Wheelchair basketball players (wheelchair users vs. non-users)	102	OR: 0.54 (p=0.05)	**II**	**Low**
Injury Location	Delaney et al. 2006 [98]	PC	Collegiate American football, ice hockey & football players (side/temporal area of the head/helmet)	69	Football: p=0.0001 Soccer: p=0.0032	**II**	**Low**

Weather season	Gissane et al. 2003 [128]	CC	Professional rugby players (summer vs. winter season injuries)	18	IRR: 1.2, p=0.7	**III**	**Low**

†populations from various sports were investigated

*recalculated IRR or inverted the original study's risk estimate and confidence interval by two of the authors (SA and SM)

PCS - prospective case series, PC – prospective cohort, RCC – retrospective case control, RC – retrospective cohort

APOE – apolipoprotein E, IRR – incidence rate ratio, RR – relative risk, OR – odds ratio, HR – hazard ratio, yr – year, X^2 - chi square statistical analysis, df – degrees of freedom

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

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

Limitations

There were several limitations to this systematic review. Studies which 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[129] 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 specifically concussion. Consequently, these studies were excluded from this systematic review.

Future Research

The investigation of risk factors is an important step toward understanding the aetiology of concussion. Although several risk factors were identified in the appraised studies, poor study methodology compromised the estimation of concussion risk for almost all the investigated risk factors, except previous concussion and match play. For this reason, prospective cohort design and consistent measures of risk should be employed in future studies. Specifically, the effect of body checking using aged 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, everal neurological disorders such as migraines, encephalitis and epilepsy [2,130] have been suggested to affect concussion risk but lacked sufficient research to be identified in this systematic review. Further studies are therefore 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 (Table 3). 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 chronic traumatic encephalopathy (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 in order to reduce concussion incidence, improve management of athletes at high risk and prevent serious health complications later on.

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Competing interest

The authors declare no competing interest, however AVS has filed patents regarding specific genetic sequence variants (not discussed in this manuscript) and injury risk of Achilles tendinopathy and anterior cruciate ligament ruptures.

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Summary: 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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