REVIEW

Preventing head and neck injury

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A wide range of head and neck injury risks are present in sport, including catastrophic injury. The literature since 1980 on prevention of head and neck injury in sport was reviewed, focusing on catastrophic and brain injury and identifying the range of injury prevention methods in use. There have been few formal evaluations of injury prevention methods. Approaches that are considered, or have been proven, to be successful in preventing injury include: modification of the baseball; implementation of helmet standards in ice hockey and American football and increased wearing rates; use of full faceguards in ice hockey; changes in rules associated with body contact; implementation of rules to reduce the impact forces in rugby scrums. Helmets and other devices have been shown to reduce the risk of severe head and facial injury, but current designs appear to make little difference to rates of concussion. Research methods involving epidemiological, medical, and human factors are required in combination with biomechanical and technological approaches to reduce further injury risks in sport.

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Sports involving body contact, projectiles, and/or high speeds are associated with a risk of head and neck injury. The personal and social costs of severe head and neck injury are high. For example, a wrestler was awarded damages of Australian $5.7 million in 2002 after sustaining a spinal injury during a training bout in 1998.[1] It was found that that the contest had not been properly supervised. Severe injuries do not always occur on the sports field; a child spectator died after being struck in the head by an ice hockey puck in the United States in 2002.[2] These two tragic examples indicate that injury prevention must be multifaceted, addressing in these cases the built environment, training, and supervision. This is a review of the effectiveness of methods to prevent head and neck injury. It is not a systematic epidemiological review or meta-analysis, rather interventions are reviewed in the context of the hierarchy of risk controls to provide examples of the range of methods available and their effectiveness. The review will focus on the prevention of mainly intracranial head injury, from concussion to catastrophic injury, and only on the prevention of spinal cord injury. Methods of preventing superficial head injury and oral injuries are not specifically reviewed.

METHODOLOGY

Literature was selected for review and inclusion in this paper using a number of criteria and tools. Medline and SportDiscus searches were conducted using keywords including: "athletic injuries", "wounds and injuries", "sports" (specific sports), "sports equipment", "head", "spinal cord injuries", "impact injury", "helmets", "brain concussion", "rule change",and "randomised controlled trials". English language papers only from 1980 were reviewed. Proceedings of sports medicine, injury, and biomechanics conferences, and texts were also searched. Preference was given to prospective, case controlled, or randomised controlled study designs. However, it was recognised that few head and neck injury interventions have been assessed using these methods. For example, the combination of the keywords "randomised controlled trials" and "athletic injuries" resulted in only four papers out of almost 25 000, none in the area of head and neck injury. The combination of "prospective studies" and "brain concussion" resulted in only five suitable papers relating to injury prevention, and all published in the last decade. Sports such as cycling, motor sports, and water sports were not formally reviewed, as the cohorts in many studies are not necessarily restricted to sport.

PROFILE OF HEAD AND NECK INJURY

Table 1 presents examples of head and neck injury profiles in a selection of sports. It can be seen that head and neck injury constitute a large proportion of injuries in contact, projectile, equestrian, and snow sports. Although attempts were made to include papers in table 1 that applied the same injury and exposure definitions, owing to a variety of definitions, it is difficult to establish the relative injury risks between each sport.

CATASTROPHIC HEAD AND SPINAL CORD INJURY

Catastrophic head and spinal cord injury (SCI) occurs in sport. In total, 497 players have died while playing American football in the Unites States since 1945; of these, 69% died from fatal brain injuries and 16% from SCI.[20] A study of deaths in football in Victoria, Australia identified nine cases of intracranial injury resulting from head impacts in the period 1968–1999.[21] In some fatal injury cases, an event exposes an underlying anatomical or physiological abnormality.

Even though the overall rate of SCI in rugby is low, there is a distinct risk in rugby associated primarily with the tackle and scrum.[22] In a recent review of SCI in Australia between 1986 and 1996, six of the 31 SCI cases occurred in

Table 1 Profile of head and neck injury risks in selected sports

Sport	Injury incidence, proportion of head and neck injury, and special issues
Rugby	19.4 lost time injuries per 1000 player hours (under 15 level to international combined); head injury 14–25%, concussion 5–15%; neck injury 2.6–7.5%, risk of catastrophic injury[3]
Ice hockey	96 per 1000 player hours (junior), 53 per 1000 player game hours; 4–18% at the professional level, 1995–2001 & concussion 2–20%; intracranial injury and blinding[4–6]
American football	40 per 1000 athletic exposures; 6.1% concussion & 0.41 concussions per National Football League game; neck injury 5%; severe and fatal injury[7–9]
Baseball	Facial injury 28%, head injury 11%, oral injury 5% in 5–14 year olds and emergency visits; leading cause of sports related eye injury in the USA[10]
Youth soccer/football	0.6–29 injuries per 1000 player hours, depending on level of play; head injury 4–20%; fatal injuries in children caused by falling goal posts; debate over concussion and heading[11–13]
Boxing	16% of injuries in professional boxing are concussion; risk of severe acute and long term brain injury[14]
Cricket	2 injuries per 1000 hours in first class[15]; head injury 3–25%; orofacial and eye injuries[15 16]
Professional horse racing	606 injuries per 1000 jockey years (1993–1996, USA); head, neck, and facial injury 19%; severe spectrum of injuries from falls and collisions[17]
Skiing & snowboarding	2–6 injuries per 1000 skier days; brain injury accounted for 29% of all injuries admitted to hospital, 50–88% of all fatalities, and in general 3–15% of all injuries.[18]; head injury 7% of all injuries[19]; collision with rigid objects, such as trees, may be fatal[18 19]

schoolboys, with an annual incidence of 1.7 per million players compared with 4.8 per million adult players for this period.[23] In the United States during the period 1970–1996, 36 of the 62 cervical spine injuries in rugby occurred in the scrum, including 14 junior players.[24 25] There is also a risk of SCI in American football, which has been associated with spear tackling, in which the tackler dives head first into the opponent.[26] Body checking, especially from behind, in ice hockey was similarly blamed for SCI in ice hockey.[6] In youth baseball in the United States, about one in four annual deaths resulted from ball to head impacts.[27] Horse racing is another sport with a high risk of head and neck injury caused by falls from the horse and impacts with the rail and the horse. Between 1975 and 2000, there were nine fatalities in professional horse racing in Great Britain and Ireland. The causes of death were, in general, brain, cerebrovascular, and thoracic injury.[28] Catastrophic injury risks exist in boxing and aquatic, motor, and snow sports as well.

PREVENTION OF HEAD AND NECK INJURY

Injury prevention methods have been categorised under headings drawn from the hierarchy of risk controls. Examples from the literature have been used to demonstrate the effectiveness of each method. For these methods to be successful, they must either be able to minimise the energy involved in impacts and collisions or reduce the forces applied to the body to levels that can be tolerated without injury.

Elimination, substitution, and engineering

In the context of formal sports, it is possible to eliminate some injury risks by elimination or substitution of hazards or engineering methods. Banning a sport is an additional approach. Sensible removal of structures from the playing field, the replacement of rigid with frangible structures, and the provision of barriers between the playing field and spectators are obvious engineering methods for preventing injuries.

Baseball balls

In baseball, softer balls have been shown to reduce the risk of head injury compared with standard balls.[29 30] Marshall *et al*[30] observed a 28% reduction in the risk of injury in baseball for games using the reduced impact ball compared with the standard ball (rate ratio = 0.72). The softest impact ball was observed to be associated with the lowest risk of injury (adjusted rate ratio = 0.52). The authors also reported on a study noting that adult and child players found it difficult to identify the differences between standard and safety balls in pitching, throwing, and batting.

Environment: ground hardness and surface

Australian rules football is a fast, kicking and running game played at professional and amateur levels across Australia and associated with a high rate of concussion. Recent studies have debated whether ground hardness is a direct factor in the aetiology of injury or whether it indirectly contributes to higher injury rates as it enables higher running speeds and higher energy impacts. Norton *et al*[31] concluded that higher game speeds resulted in more collisions and a higher risk of injury. No study has examined the benefits of a ''slow'' ground. With regard to direct head impacts and concussion, Naunheim *et al*[32] observed significant differences in the impact energy attenuation properties of grass and two types of artificial surfaces and proposed that the artificial surface in a domed stadium might contribute to the incidence of concussion in American football.

Training

Training to improve strength, fitness, and individual and team skills is an accepted part of sport. Whereas training programmes have been shown to reduce lower limb injury, for example, the benefits of neck strengthening, skills, or fitness in reducing head and neck injury have not been formally addressed. Considering the high associations between body contact and injury in American football, rugby, and ice hockey, it is possible that skills may reduce injury. Skills to track a ball and avoid ball contact and mishits would also help to reduce neck and head injury; however, they have not been formally assessed.

Administrative controls (laws and rules)

Rules are one of the most common methods used to prevent injury, but there have been few structured intervention studies that have identified the benefits associated with specific rules.

Pre-participation screening for head and neck injury

One method for preventing head and neck injury would require participants to undergo medical screening programmes to identify players at risk of injury because of anatomical abnormalities or genetic markers, and mandate criteria for excluding player participation. Similar procedures can be applied to return to play decisions. Although this method does not control the hazard, it may help to reduce injury risks. The role of pre-participation screening in head injury assessment is a critical step in optimal management of athletes. Ascertainment of confirmed concussive injuries is important in understanding a player's risk of injury and future management. Genetic screening may also need to be considered in this setting as our understanding of the influence of inherited factors in injury outcome increases. By far the most important tool in this setting is a baseline neuropsychological assessment, which then becomes the basis by which future return to play decisions are made. Unfortunately, although pre-participation examinations are widely performed, there are no evidence based guidelines to direct doctors as to the minimum requirements for the baseline assessment of head injury at this time. In addition, there are important medicolegal considerations with regard to the value of a documented medical assessment at both the start and end of an athlete's career with any team.[33]

In some situations, congenital spinal canal stenosis has been postulated as a risk factor for cervical cord injuries. Although the risk of future cord injury may be increased when canal stenosis is present and the athlete has previously sustained a cord injury, this increased risk cannot be quantified with any certainty.[34–36] Furthermore, the risk of future cord injury in an asymptomatic athlete with canal stenosis is unknown at present. Advice on the risk of injury in this latter situation is at best anecdotal and no intervention studies are reported in the literature.

The rugby scrum

The rugby scrum has received substantial attention over the years with regard to SCI. A rugby scrum consists of two packs of eight players divided into the three front row, two back row and three loose forwards. The front rows of each team's scrum pack engage through their heads and shoulders in a forceful driving motion. This can result in high axial compressive neck forces combined with a bending moment and/or shear forces; during the 2003 Rugby World Cup there was one case of cervical dislocation during a scrum engagement which was a career ending injury. Milburn[37] measured the forces applied to an instrumented scrum machine, and found that the total horizontal forward force on engagement ranged between 4.4 kN for high school players to 8 kN for the Australian national team. After the initial engagement, the sustained force decreased by about 20%. The forces on engagement have the potential to exceed axial neck load and bending moment tolerance limits. As a result, scrum laws for under 19 year olds are now designed to eliminate an impact on engagement and permit each front row to orient itself well, thus reducing neck loads. No study has reported on the effectiveness of the under 19 law, although it is widely viewed as being successful.

The tackle and body checking

The tackle in rugby and Australian and American football, and body checking in ice hockey are associated with risks of minor to severe impact injury, including skull fractures, brain injury, and SCI. In rugby, approximately half of all injuries arise in the tackle. Factors that may give rise to injury risks, including SCI and concussion, in the tackle include: high tackles; high velocity tackles; tackles in which the tackler may have been in the peripheral vision of the ball carrier; "big hits" in which the ball carrier is tackled by more than one player; a general lack of skill for the tackler.[38–40] Apart from high tackles and spear tackles, where the ball carrier is speared head first into the ground, the other types of tackle are legal. Body checking in ice hockey, especially involving the head, has led to a concern that this form of contact should be eliminated through rule changes because of its association with head injury.[41] As with spear tackling in American football, which was made illegal, there is a view that the use of helmets has increased hazardous play through players' perceptions that they are at a lower risk of injury, often referred to as risk compensation. In American football, the intentional use of the helmet or faceguard as the primary point of contact has also been made illegal.[20] It may also be necessary to implement rules to accompany the widespread use of helmets. Apart from reducing tackle related injuries through rules, no study has reported on the effects of tackle training as a method for preventing injury.

Personal protective equipment: helmets

Helmets and padded headgear are used in many projectile and contact sports to prevent head injury. The recent meta-analysis by Thompson *et al*[42] of pedal cycle helmets in transport and recreation showed that lightweight helmets are effective in preventing head and facial injuries. In some sporting competitions it has become mandatory to wear a helmet and/or faceguard—for example, baseball, softball, American football, and ice hockey. Recently, there has been much debate over the use of padded headgear in soccer. Helmets are designed to attenuate the impact energy and distribute the impact force applied to the head. Helmet attachments, such as faceguards, are also used to prevent orofacial injury. If a helmet can reduce the head impact force and head's acceleration to below relevant tolerance levels and under sport specific impact scenarios, then a helmet can function to reduce the risk of injury. The widespread use of helmets indicates that training and laws are not sufficient to prevent head injury, as even talented athletes suffer from head injuries.

Helmets in American football and ice hockey have evolved from padded headgear to helmets comprising a hard shell, a liner, and a faceguard. Canadian and NOCSAE standards for ice hockey and football helmets respectively were established in the early 1970s. Typically, standards' tests consist of dropping a helmeted headform on to an anvil and measuring the headform acceleration; the lower the acceleration the greater the impact energy attenuation for a specified test.

Levy *et al*[20 43] reported that the introduction of laws to control the use of the head in blocking and tackling, and the implementation of NOCSAE helmet standards in American football, has resulted in a 74% decrease in fatalities and 84% reduction in serious head injury since 1976.

Using historical records, Biasca *et al*[6] reported that the introduction of rigorous standards for ice hockey helmets combined with increased wearing rates has been responsible for the reduction in fatal and serious head injury, but recently there has been an increase in mild brain injury. In junior A ice hockey, full faceguards were found to provide a 4.7 times reduction in eye injuries and a non-significant reduction in the rate of concussion from 12.2 to 2.9 concussions per 1000 player hours compared with no faceguard.[44] In university level ice hockey, the use of full faceguards was found to reduce the number of games missed because of concussion, but not the incidence of concussion, compared with the use of half faceguard.[45] Faceguards have also been shown to reduce the incidence of oculofacial injury in youth baseball by 28% in a non-randomised prospective cohort study in 1997.[46]

Studies into the effectiveness of helmets in sports where the use is not mandatory are emerging. Ski helmets have

What is already known on this topic

It is well accepted that helmets have a role in preventing serious head injury, but to date only rules and changes in player behaviour appear to be effective in preventing serious neck injury.

What this study adds

This study provides an integrated analysis of the range of methods available to prevent head and neck injury in sport.

been found to be effective for adult and child skiers and snowboarders, reducing the risk of severe head injury by up to 56% and 29% for all head injury.[47 48] However, a potential increase in neck injury associated with helmet use in snow sports was also noted.[47] Studies of the effectiveness of cricket helmets have been confined to the laboratory and indicate that the level of protection is greatly reduced with high speed ball impacts.[49] Research to date, both field and laboratory, indicates that padded headgear does not reduce the incidence of concussion in rugby union football.[50–52] Jones *et al*[53] observed a general reduction in superficial head injuries and blood injuries with headgear wearers, but the results were not consistent across player positions. Survey responses of under 15 male rugby players and as yet unpublished studies on a wider age group of rugby players suggested that players believe that they can tackle harder and play more confidently while wearing headgear.[51] As the action of tackling is responsible for half of all rugby injuries, this combination of perception and biomechanical performance is of concern. Laboratory testing of a thicker and denser version of padded headgear showed that impact energy attenuation could be improved, but possibly not to a level consistent with the impacts observed to produce concussion in unhelmeted footballers.[54]

The evidence indicates that helmets in American football and ice hockey are successful in preventing severe head injury—for example, skull fractures—but that their role in preventing mild injury such as concussion is unclear. To date no study has reported on a helmet that is effective in preventing concussion.

CONCLUSIONS

A wide range of head and neck injury risks are present in sport. There have been few studies of injury prevention methods. One reason for this may be that interventions have been introduced as a rapid response to an acknowledged problem, and, in some cases, rule changes or mandatory wearing of helmets has meant that control groups no longer exist. Helmets and other devices have been shown to reduce the risk of serious head and facial injury, but current designs appear to make little difference to concussion. Neck injury has been addressed through laws and skill development, with little formal evaluation. Research methods involving epidemiological, medical, and human factors are required in combination with biomechanical and technological approaches to reduce further injury risks in sport.

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ECHO

Artificial altitude training creates concern in Australian football

Please visit the *British Journal of Sports Medicine* website [www.bjsportmed.com] for a link to the full text of this article.

A sense of unease pervades some quarters of Australian football over the Australian Football League's decision not to ban hypoxic air machines for enhancing performance by simulating high altitude conditions. An ethicist's view is that the machines should be banned only for reasons of ensuring fair competition among players.

Hypoxic air machines provide a nitrogen rich environment, which is thought to boost the production of red blood cells and their oxygen transporting ability. The parallel with erythropoietin, which does the same chemically, is disquieting to some but so far disproved scientifically. So the league has ruled that use of the machines does not break its antidoping code or its rules.

Those in favour of the machines point out that training at altitude or in hypoxic machines is widespread, though the documented track record in improving performance is unconvincing. The machines merely provide a high altitude environment to try to boost training and are not a biomedical short cut to improved performance like chemical enhancers, their advocates say. Arguments against their use are also rather undermined by recent realisation that another club in the league is doing hypoxic training the simple way—its members swimming laps while holding their breath—which is said to mimic altitude training

So, should hypoxic environments be permissible forms of performance enhancement in sport—alongside exercise, training, and nutrition? Ultimately it's all down to what is judged as fair competition.

▲ Spriggs M. *Journal of Medical Ethics* 2005;**31**:112–113.