In: Sports Injuries
Editor: Gabrielle Hopkins
ISBN: 978-1-63463-305-5

Chapter 3

PROTECTIVE HEADGEAR FOR RUGBY, AUSTRALIAN RULES FOOTBALL AND SOCCER

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ABSTRACT

Rugby, Australian Rules football (ARF) and soccer have high participation rates in numerous countries. A consequence of contact and collision sports is a notable injury rate and of particular concern is head injury, especially concussion. A countermeasure intended to reduce head injury prevalence in these football codes is non-obligatory protective soft-shell headgear. The adoption rate of this type of headgear for rugby (7 to 27%) was found to be higher than for ARF (2 to 8%). The main reason given for not wearing headgear was discomfort. Laboratory studies of soccer headgear demonstrated significant impact attenuation during scenarios simulating head to head contact. Laboratory studies of ARF and rugby headgear have shown that thickness is directly related to impact attenuation and that the type of headform and impact surface greatly influences the test results. Randomised controlled trials with teenage

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rugby union players did not find headgear significantly reduced concussion rate or other head injuries. There was one attempted randomised controlled trial with ARF but was unable to be completed because of poor compliance with wearing headgear; this is a major challenge for researchers. One retrospective study found that soccer headgear reduced the proportion of concussions for collegiate athletes. There is some evidence as well as inconsistent results from prospective and retrospective studies that headgear may reduce concussion or superficial head injuries in rugby. The weight of the evidence suggests that the headgear assessed so far cannot be relied on its own to significantly reduce concussion rate but should not be dismissed completely.

1. INTRODUCTION

Football codes such as rugby, Australian Rules football and soccer are highly popular in many countries throughout the world but as with other contact or collision sports, injuries do occur. Concerted effort is required to prevent and manage injuries, particularly head injuries like concussion. Concerns have been raised about the short-term and potential long-term consequences of repeated concussions and even sub-concussive impacts [1, 2]. One approach to try and reduce head injury incidence and severity in sport is the utilisation of protective equipment. Non-mandatory padded headgear as opposed to hard-shell helmets have been approved for these football codes by the sport governing bodies [3-5] as long as they don't pose an injury hazard to any player. While not main stream practise, there are reports of sporting clubs and schools requiring their junior athletes wear protective headgear while playing rugby, ARF or soccer [6-8]. There are also cases of professional athletes in these sports who wear headgear on return to play following face or skull fractures or concussion [9-12]. Sustaining repeated concussions has been reported as contributing to the retirement of athletes from professional soccer among other sports [13].

Sports medicine and public interest in protective headgear is usually intensified after media reports of high-profile or junior athletes sustaining head injury while participating in the football codes without compulsory headgear [14]. There is a need to synthesise the current body of knowledge related to protective headgear for these football codes so as to assist those involved to make informed decisions as to the role of non-obligatory protective equipment. The objectives of this review are to (1) describe the adoption rates and attitudes to non-mandatory protective headgear in rugby, ARF and soccer; (2) report on the biomechanical evaluation of the headgear; (3) evaluate the effectiveness of the headgear on injury incidence; and (4) identify areas for future research. The review was centred on peer-reviewed journal articles identified from electronic literature searches using MEDLINE, CINAHL and SPORTDiscus databases up to September 2013, using the following search terms in various groupings: 'headgear', 'head guard', 'head protector', 'helmet', 'rugby', 'Australian', 'football', 'soccer', 'head', ' injuries' and 'concussion'. Additional studies were identified from the cited reference lists of the articles found by the electronic searches.

2. Head Injury Incidence

Head injuries in sport may encompass an injury spectrum range from superficial soft tissue such as lacerations and abrasions, through to concussion, skull fractures and uncommon catastrophic brain injuries such as sub-dural haematoma and intracranial haemorrhage [15]. The incidence of head injury in rugby, ARF and soccer has recently been reviewed and reported. Head injuries in soccer across all levels of play accounted for 4 to 20% of all injuries while concussion accounted for 3%, with a rate of 0.06/1000 hr for professional European soccer, 0.59 per 1000 hr for high school level and 1.08 per 1000 hr at the college level [16]. For ARF, at the community level the incidence of head injuries was 2.6/1000 hr, with concussion accounting for 4.3% of all injuries; at the elite level, concussion was one of the most common injuries with an incidence rate of 5 to 6/1000 hr [17] and multiple concussions to the same player throughout their career was not infrequent [18]. Rugby also had a notable proportion of head injuries, 14 to 25%, with concussion accounting for 5 to 15% of all injuries and occurring at a rate of 6.9/1000 hr for adolescents [16].

3. Protective Headgear

Headgear are designed to attenuate impact energy and distribute impact force applied to the head, usually achieved by energy-absorbing material such as a closed-cell foam liner compressing to absorb force, decreasing force to the head which reduces acceleration of the head. If the headgear can reduce head impact force and acceleration to below injury tolerance levels under sport specific impact scenarios then they can reduce injury risk [15]. There are a number of considerations that go into the design and construction of protective headgear and often there is a trade-off in certain parameters because of conflicting requirements. For instance, the need for a fastening system at the back, ventilation, uninterrupted vision and cut out sections over the ears for hearing will compromise coverage to certain parts of the head for rugby and ARF headgear. Other requisites usually include: the need to be flexible to conform to the contours of the head for a stable and comfortable fit; lightweight; aesthetics; affordability; and resilience to be able to withstand multiple impacts.

Recently, protective headgear has been designed for use in soccer, particularly for young male and female players [7]. Most of the soccer headgear resembles an enlarged headband, so their low profile is unlike the traditional ‘helmet’ look. There is usually an impact absorbing foam encased in an exterior fabric and sometimes with plastic inserts. Design considerations include protection of the impact areas such as the forehead and temple, lightweight, ventilation, moisture absorbing, adjustable fit and possibly ports to accommodate ponytails and other hair wearing options. Although the majority of soccer headgear has a low profile design, they are the more traditional fuller coverage headgear, one version resembled that used in martial arts [19] and others are rugby-type headgear that have been worn by players that have suffered severe concussion [12] or skull fracture [9].

4. UTILISATION AND ATTITUDES TO NON-MANDATORY HEADGEAR

There have been a number of studies on the use and attitudes to protective headgear in rugby and ARF (Table 1) with many investigating a range of playing levels [8, 20, 22, 25], age groups [8, 20, 22-25] or gender [8, 20, 22]. All but one of the studies [22] was of retrospective design and the examined period for the majority of the studies was the previous playing season [20, 21, 23, 24]. There were 5 studies surveying rugby participants [8, 20-22, 25] and 2 studies on ARF [23, 24]. No published studies on the usage rate and attitudes to soccer protective headgear were found, possibly because of the recency of their utilisation in the sport.

Table 1. Adoption rates and attitudes to voluntary usage of protective headgear

Study (year)	Sport, level, participants	Study design	Percentage that wore headgear	Main reasons for wearing headgear	Main reasons for not wearing headgear
Gerrard et al. (1994) [20]	RU, club level senior A, B, men, senior women, U/21, school boys and girls. 250 M 92 F	Retrospective questionnaire at the end of 1992 season	20%	To prevent injury (57%); because of previous injury (53%); based on medical advice (21%). Could give more than 1 reason	Not reported
Finch et al. (2001) [21]	RU, 10 randomly selected school teams, U/15. 139 M	6 teams assigned headgear. Survey at the end of the 1999 season.	79% Data collected during a trial of headgear	Feel safer (54%) Did not want to get an injury (42%).	Discomfort (61%)
Marshall et al. (2001) [22]	RU, club level senior A, B, men, senior women, U/21, school boys and girls. 240 M, 87 F	Prospective, weekly interviews during 1993 season	14% overall. School boys 33%. Loose forwards position highest users 23.5%	To prevent injury and because of past injury.	Not reported
Pettersen (2002) [8]	RU, high school, university, community, national. 39 M, 24 F players and 7 M, 2 F coaches.	Questionnaire on headgear and effectiveness on preventing concussion	27% overall (most of these from the national team 10/17)	62% of players and 33% of coaches thought it could prevent concussion.	Not mandatory, uncomfortable and expensive
Study (year)	Sport, level, participants	Study design	Percentage that wore headgear	Main reasons for wearing headgear	Main reasons for not wearing headgear
Finch et al. (2003) [23]	ARF, community-level, 3 senior and 1 junior teams, 70 M	Pilot study, retrospective questionnaire at the end of the 2000 season	8%	To prevent injury. 80% of non-users would wear one if they had an injury and 36% if it prevented injuries	Discomfort (47%), didn’t like wearing it (42%) and didn’t need to (23%).

Table 1. (Continued)

Study (year)	Sport, level, participants	Study design	Percentage that wore headgear	Main reasons for wearing headgear	Main reasons for not wearing headgear
Braham et al. (2004) [24]	ARF, community-level, senior and junior, 301 M	Retrospective questionnaire at the end of the 2000 season	2%	Safety and protection of previous injury. 67% of non-user would wear one if they had an injury, 32% if it was mandatory by their club and 26% if it prevented injury.	Didn’t like wearing it (45%) and discomfort (41%)
Comstock et al. (2005) [25]	RU, tournament with varied levels of play, adults, 234 F	Retrospective questionnaire on most recent 3 months of play	7% (only forwards always worn headgear)	Injury prevention (85%)	Not reported

ARF = Australian Rules football; F=female; M=male; RU=rugby union; U = under.

The general overall adoption rate of protective headgear in rugby ranged from 7 to 27% [8, 20, 22, 25] and was higher than that for ARF 2 to 8% [23, 24]. There was one study [21] that reported a usage rate of 79% for school boys' rugby but this was for a trial that provided the headgear as part of the investigation so the figure is a vast overestimation of the general wearing rate.

One reason for the lesser rate of headgear usage in ARF could be the perceived risk of head injury by most ARF participants is lower and therefore there is no compelling motivation to wear headgear [23]. Playing position influenced headgear usage in rugby with forwards for both genders more likely to wear them because of their greater injury risk [22, 25]. Males were more likely to adopt headgear than female rugby participants probably due to their different styles of play, higher impact forces and injury incidence [22].

Not surprisingly, the main reason the participants gave for wearing headgear was to prevent injury [20-25]. Also featuring prominently as a reason for headgear usage was a previous injury [20, 22, 24]. This might allow participants to continue to play before full recovery from an injury, prevent the injury becoming more severe or avert recurrent injury [25]. The main reason given for not wearing headgear was discomfort [8, 21, 23, 24]. Other prominent reasons given were didn't need to or non-mandatory [8, 23]. Although discomfort was cited as a leading reason for not wearing headgear, improvement in comfort was not stated as a key factor that may sway non-users to adopt headgear. The primary incentives for a number of ARF participants that did not wear headgear to wear one would be if they had an injury or if it prevented injuries [23, 24].

5. Biomechanical Assessment of Impact Attenuation of Soccer Protective Headgear

Soccer is unique in the regard that it is the only contact sport that purposefully uses the head to control and progress the ball [26]. Early concerns in soccer were that repetitive heading, particularly by younger players, may be a risk factor for cognitive impairment, so the initial focus was to evaluate the soccer protective headgear in experimental set ups that simulated the conditions of soccer heading [7, 27]. It can be seen from Table 2 that there have been four laboratory studies on impact attenuation of soccer headgear during heading a soccer ball [7, 19, 27, 28]. Tests have been reported on six brands of headgear: Soccer Docs; Kangaroo which was similar to martial arts headgear, foam liner encased in vinyl, overall thickness about 20mm, forehead region 28 mm [19]; Head Blast had foam with thin plastic sheet embedded, fabric backing, plastic front cover, about 8 mm thick [19]; Head'r; Full90 (Headers) comprised of foam bound to fabric exterior, about 11 mm thick [19]; and Protector which had a hard plastic insert backed with foam within terry-cloth headband and similar thickness to Headers [7]. Details of the type of foam and densities in the headgear were not available.

The testing methods have involved the use of surrogate headforms [19, 27] or a force platform [7] with ball contact speeds ranging from 9 to 30 $m.s^{-1}$ and human volunteers tests with low speed ball contacts of 6 to 9. 8 $m.s^{-1}$ [19, 28]. The lower ball speeds have been reported as being common in general soccer play and heading [7, 27]. Three of the studies [7, 27, 28] found that headgear could reduce peak acceleration or force by 11 to 17% but they only considered linear acceleration from ball contact and the findings may be gender specific. Female volunteers actually experiencing greater head acceleration while wearing headgear possibly because of their less head mass and neck strength which may partially explain the greater incidence of concussion in female soccer players than male [28]. The one study [19] that reported no significant reduction in impacts from ball contact used the most biofidelic headform, highest ball speeds, considered rotational acceleration in its injury index and surmised that headgear was ineffective for head to ball contact because of the large amount of ball deformation relative to headgear thickness. Two of the studies [19, 27] which included tests on the Kangaroo brand headgear that was twice as thick as all the others, blinded their results so comparison between brands was limited. One study [7] found that all 3 brands tested Headers, Head Blast and Protector reduced impact with no difference between them. Another study [28] found that during tests with male volunteers the slightly thicker Full90 headgear displayed a greater reduction in linear acceleration than the Head Blast headgear. It is important to note that overall, the accelerations, injuries indices and risk of head injury from the ball contact testing with and without headgear were low [19, 28]. Heading the ball may be considered low acute injury risk compared to head contact with rigid body parts. One study [19] simulated head to head clashes which along with contact with other body parts or the ground is now realised to be a more likely

Table 2. Laboratory evaluation of impact attenuation of soccer protective headgear

Study (year)	Headgear brand	Laboratory test	Significant findings ($p<0.05$)
Naunheim at el. (2003) [27]	Soccer Docs, Kangaroo, Head Blast, Head'r	Headgear placed on rigid magnesium headform with triaxial accelerometer and flexible neck; high and low pressure soccer balls projected at 9, 12, and 15 $m.s^{-1}$. Five trials for each headgear and bare headform (control)	Peak acceleration values with and without headgear were very low (15 to 30 g). Headgear reduced peak acceleration (12 to 17%) at highest speed and pressure. No difference or protection at low or moderate speeds or low pressure.
Broglio et al. (2003) [7]	Headers (name now changed to Full90), Head Blast, Protector	Headgear attached to a vertically mounted forceplate and soccer balls projected at 15.6 $m.s^{-1}$. Fifty trials on each headgear and bare forceplate (control)	All 3 reduced peak force (11 to 13%) with no difference between them. Protector reduced time to peak force (23%) and impulse (11%). Full90 increased impulse (5%).
Withnall et al. (2005) [19]	Full90, Head Blast, Kangaroo	Headgear attached to Hybrid III headform and neck which measured linear and angular acceleration while impacting another Hybrid III headform at two sites at 2 to 5 $m.s^{-1}$; ball impacts with headgear at 10,20 and 30 $m.s^{-1}$; human volunteer with a bite plate with accelerometers heading a ball at low speeds of 6 and 8 $m.s^{-1}$	Headgear on average reduced head to head impact peak acceleration and HIPmax by 33%; maximum bare head acceleration was 169 g. Accelerations (15 to 60 g), HIPmax and concussion risk from ball impacts with and without head gear were generally very low. No overall significant reduction in impacts from ball contact for Hybrid III or volunteer tests.
Tierney et al. (2008) [28]	Head Blast, Full90	Headgear was worn by 44 volunteers (29 women, 15 men) with a mouthpiece triaxial accelerometer while heading a ball projected at 9.8 $m.s^{-1}$. Heading was also done without headgear (control)	Overall, peak acceleration (15 to 22 g) and HIC (14 to 20) values with and without headgear were very low. Head Blast reduced linear acceleration by 11% and Full 90 by 17% for men. Headgear increased acceleration by 7 to 8% for women. Women showed greater head acceleration (10 to 44%) than men with headgear and without.

HIC = Head Injury Criteria; HIPmax= Head Impact Power.

mechanism for concussion than heading the soccer ball [29, 30]. It was demonstrated that headgear reduced acceleration and the index for mild brain injury by a third during head clashes and it was concluded that headgear was effective in reducing impact between two stiff objects such as in head to head contact [19].

There is a standard for testing headgear used in soccer [31]. Drop tests are conducted with a Hybrid III headform and neck assembly, total mass of 8.8 kg and the resultant linear acceleration is measured. The impact area is an angled 50 mm band encircling the head. Three different impact scenarios are considered, heading the ball impacts are not addressed. The first test is an impact at 2.0 $m.s^{-1}$ with a steel post anvil to represent a goal post. The second test involves impact at 3.8 $m.s^{-1}$ with another Hybrid III headform. The final scenario is impact at 2.5 $m.s^{-1}$ with a firm modular elastomer programmer (MEP) pad on top of an anvil to simulate contact with the ground.

For all 3 test scenarios, the peak linear acceleration should not exceed 80 g. The standard also specifies a multiple impact test on the MEP pad; 5 impacts on the same spot with 75 s intervals and the peak acceleration of the final drop should not exceed 15% of the first drop. The second test scenario of the standard was similar to that used by one of the laboratory studies [19] which found that at an impact speed of 4 $m.s^{-1}$ only one of the 3 headgear tested did not exceed a peak acceleration value of 80 g. This study included a headgear that was twice as thick as the other two but since the data was blinded, the characteristics of the best performing headgear could not be confirmed.

6. Biomechanical Assessment of Impact Attenuation of Rugby and ARF Protective Headgear

Several headgear for rugby and ARF have undergone biomechanical testing with the majority originally intended for rugby (Table 3). The two studies [32, 34] that evaluated the most headgear blinded the brand names but some information on construction and composition was available. The thickness of the headgear ranged from 7 [33] to 16 mm [35], ethyl vinyl acetate [34] or polyethylene [35] foam were commonly used and foam density ranged from 48 to 87 $kg.m^{-3}$ [34].

Table 3. Laboratory evaluation of impact attenuation of rugby and ARF protective headgear

Study (year)	Headgear	Laboratory test	Significant findings ($p<0.05$)
McIntosh and McCrory (2000) [32]	8 headgear from 6 manufacturers. Brand names blinded, limited details on composition.	Headgear attached to both rigid magnesium and Hybrid III headforms and impacted a rigid anvil at speeds of 2 to 3.4 $m.s^{-1}$; impact energies of 9.8 to 29.4 J. 5 repeated drops at same site with impact speed of 2.4 $m.s^{-1}$ also conducted.	For impact speeds of 3.1 $m.s^{-1}$ and greater, all headgear exceeded the proposed acceleration (150 g) and HIC (1000) thresholds and deemed unlikely to prevent concussion. Repeated drops increased peak acceleration from 5 to 50%.
Knouse et al. (2003) [33]	2 types of rugby headgear, 10 samples of each: Canterbury Honeycomb 10 mm thick, high-density closed-cell foam and 96 grams; Gilbert Vanguard 7 to 8 mm thick, larger continuous sections and 74 grams	Headgear attached to Hybrid III headform and impacted a MEP pad on top of an anvil at a speed of 2.4 $m.s^{-1}$ 10 repeated drops on the side and back of the headgear also conducted.	Highest peak acceleration (116 g) and GSI (419) values were all lower than those assumed to cause head injury. Side of the headgear offered greater impact attenuation than the back. Repetitive drops increased peak acceleration from 11 to 56%
Hrysomallis (2004) [34]	7 rugby and ARF headgear, brand names blinded: thickness ranged from 8 to 15 mm, all comprised of ethyl vinyl acetate foam with a general density range of 48 to 87 $kg.m^{-3}$	Headgear attached to NOCSAE headform and impacted a 1.3 cm MEP pad on top of an anvil at a speed of 4.1 $m.s^{-1}$; impact energy of 56 J. Impacts to the front, side and top were conducted.	Headgear on average reduced HIC values by about 50% compare to bare headform impacts. Headgear thickness correlated with HIC values for side impacts ($r=-0.8$). Best performing headgear had the greatest thickness and foam density and only one to register HIC values of less than 1000 and peak accelerations less than 200 g for side and front impacts.
McIntosh et al.(2004) [35]	Albion Headpro model for ARF, modified: 12.5 mm thick polyethylene foam density of 65 $kg.m^{-3}$ plus 2 mm ethylene vinyl acetate insert; Canterbury Honeycomb for rugby, standard: 10 mm thick 45 $kg.m^{-3}$ polyethylene foam; Canterbury Honeycomb, modified: 16 mm thick 60 $kg.m^{-3}$ polyethylene foam	Headgear attached to a rigid magnesium headform and impacted a rigid anvil on the front and side at speeds of 2.4 to 3.4 $m.s^{-1}$; impact energies of 14.7 to 29.4 J. Six repeated impacts to same site also conducted.	The modified, thicker Canterbury headgear reduced peak acceleration by about 75% to 78% for side impacts to below 200 g at 2.4 and 2.8 $m.s^{-1}$. Albion outperformed the Honeycomb at 3.1 and 3.4 $m.s^{-1}$ but both tended to exceed 200 g. Repeated impacts at the same lateral site at 3.4 $m.s^{-1}$ increased peak acceleration by 21 to 51%.

g = acceleration of 9.8 $m.s^{-2}$; GSI = Gadd Severity Index; HIC = Head Injury Criteria; J = Joules; MEP = Modular Elastomer Programmer; NOCSAE = National Operating Committee on Standards for Athletic Equipment.

The headforms used to measure linear acceleration for the impact tests have been rigid magnesium [32, 35], Hybrid III [32, 33] or NOCSAE [34], with the latter two yielding headforms considered to be more biofidelic [36]. The impacting surface has been either a rigid steel anvil [32, 35] or a firm 1.3 cm MEP pad on top of the anvil intended to simulate the playing surface [31]. Since the side of the head has been identified as the most frequent location for impacts that produce concussion in rugby and ARF [37], this site is a commonly assessed region of headgear; tests have also been carried out to the front and top of the headgear. Impacts have been performed to the back of the headgear [33] but because of the posterior fastening design of most headgear, this comprises the amount of padding [34] and protection at this region [33]. Impact speeds during drop tests ranged from 2 to 4.1 $m.s^{-1}$ [32, 34] with 2.4 $m.s^{-1}$ being frequently included [32, 33, 35] because the testing was aligned with the International Rugby Board (IRB) standard for headgear [5] that specified a drop height of 30 cm which produced that impact speed. It is now acknowledged that the impact speeds in sport may be greater than those simulated in these tests [35]. The highest test speed utilised 4.1 $m.s^{-1}$ was to generate an impact energy of 56 J [34] that had been shown to result in concussion in ARF or rugby [37]. Peak linear acceleration of the headform has been the primary parameter investigated; other parameters which have been used as injury risk indicators such as GSI [33] and HIC [32, 34] are derived from the impact acceleration and include a temporal component. One of the limitations of the testing was it did not account for rotational acceleration which along with translational acceleration [38] can produce head injuries such as concussion [39]. Doubt has been raised as to whether protective headgear can decrease rotation [16] but limited investigation has been conducted in this area. There is some indirect support that headgear can influence rotation from the only laboratory assessment [19] that consider rotational acceleration in its head injury index and found that soccer protective headgear reduced it by 33%.

Protective headgear can reduce the magnitude of the impact acceleration and related injury indices but whether the reduction is sufficient to significantly reduce injury risk is open to interpretation. The first investigation [32] into the performance of rugby and ARF headgear concluded that they were unlikely to lessen the probability of head injury such as concussion. The type of headform and impact surface has a dramatic effect on the test results and whether the headgear is deemed likely to prevent injury. This can be illustrated by comparing the acceleration values generated when the same headgear is tested using rigid and non-rigid components. The standard

Canterbury Honeycomb headgear was assessed in one study [35] using a rigid magnesium headform impacting a steel anvil at 2.4 $m.s^{-1}$ and for a side impact produced peak acceleration of 276 g and for 6 repeated impacts on the same site generated peak acceleration of 399 g. If 200 g was considered the injury threshold then this headgear would be considered inadequate to reduce injury risk. When the same headgear was evaluated in another study [33] using the Hybrid III headform impacting a 1.3 cm MEP pad on top of the steel anvil at the same speed and site, the peak acceleration was 44 g and after 10 repeated impacts it was 70 g, well below 200g and only 16 to 17.5% of the acceleration values from tests with the rigid components.

Headgear thickness was related to impact attenuation capability. The best performing headgear had the thickest padding and high density foam [34, 35] and it appears that headgear needs to be at least 15 mm thick to have any scope of providing adequate protection. The design and construction can influence fit and impact dissipation; the honeycomb configuration with small, individual geometrical sections of padding may be more flexible and allow for a better fit while headgear with longer, continuous sections of padding may be better at dissipating impact over a greater area [35]. The impact energy attenuating foam used in the headgear needs to be resilient because of the prospect of receiving repetitive impacts. Test results revealed that repeated impacts to the same site may increase acceleration by up to 50% or more [32, 33, 35], indicating that the foam does not reconfigure to its original thickness but remains slightly compressed, decreasing its impact attenuating capacity. Most of the headgear assessed to date has comprised of closed-cell foams. Future research should consider evaluating other materials, for instance, Sorbothane®, a viscoelastic polyether-based polyurethane which has recently been incorporated into headgear [40].

The only standard that is related to headgear used in rugby or ARF is by the IRB which is the world governing and law-making body of the game of rugby union [5]. The regulations for IRB approved headgear stipulate that the headgear cannot be thicker than 10 mm or have a foam density greater than 45 $kg.m^{-3}$. When the headgear is attached to a rigid headform and dropped from a height of 30 mm onto a rigid anvil at an impact speed of 2.4 $m.s^{-1}$, the resultant peak acceleration should not be less than 200 kg. The standard actually limits the impact attenuation ability of the headgear for rugby union. Headgear approved by this standard are intended to be effective against superficial head injuries but have insufficient padding and offer minimal protection against more severe head injuries such as concussion. The intention is likely to be that rugby union players don't feel invincible with the IRB approved headgear and engage in risky behaviour. It has been recognised that the absence of a well-conceived international standard for headgear for rugby and ARF creates a deficiency in the pursuit to appraise headgear and avert the gamut of head injuries, particularly concussion [32]. Due to the complex nature, there remains deliberation about injury tolerance levels but it has recently been proposed that for headgear to be effective in reducing concussion risk in Australian football they would need to protect against head change in velocities of up to 7 $m.s^{-1}$ and reduce head resultant linear and angular acceleration to below 50 g and 1500 $rad.s^{-2}$, respectively [41]. Further research is required to fully establish validated injury tolerance levels for concussion in the various football codes, which would include the incorporation of rotational acceleration.

7. Influence of Protective Headgear on Head Injury Rate

There have been a number of studies on the effect of headgear on head injury occurrence with the vast majority involving rugby union (Table 4). There has been only one investigation on soccer [48], one attempted on ARF [44] and none reported for rugby league. For soccer there is low-level evidence from a retrospective, cross-sectional study of adolescent soccer players that found soccer headgear use was associated with about a 60% reduction in the risk of sustaining a concussion and reduced risk of other head injuries [48]. The findings needs to be considered in light of the limitations of the study design, it involved only one soccer club, headgear use was not randomised and there was a reliance on memory recall to report injuries.

The intended controlled trial on the effectiveness of headgear for ARF [44] was unable to be completed because of the low adoption rate of headgear by the participants. This highlights that compliance is a major challenge for researchers when attempting to investigate the efficacy of non-mandatory protective equipment. In spite of this potential obstacle, prospective, controlled trials have been conducted with teenage rugby union participants [42, 49]. The first study [42] provided headgear to the intervention group if they weren’t already wearing their own. It was found that the players that wore headgear did not show a significant reduction in concussion rate but it was

Table 4. Epidemiological studies of the influence of protective headgear on head injury rate

Study (year)	Sport, level, participants	Study design	Headgear details	Head injuries	Significant findings ($p<0.05$)
McIntosh and McCrory (2001) [42]	Rugby union, U/15 A grade, 16 teams, 294 M	Prospective , controlled, 1 season, 1179 player exposures with headgear and 357 without	Albion Body Pro or Madison Elite Rugby or their own	Concussion	Headgear did not reduce concussion rate
Jones et al. (2004) [43]	Rugby union, i) Emergency department presentations, 164 cases. ii) 1999 Rugby World Cup, 20 national teams, 547 M	i) Case-control study: cases being injured players (12.8 % headgear wearers) and controls (21 % headgear wearers) being same position opponent ii) Cohort study: video review, 41 games, 277 player exposures with headgear and 1333 without	Not reported	Head and face lacerations, abrasions or fractures	i) Headgear did not reduce injuries ii) Headgear decreased risk of bleeding head injuries among forwards (OR = 0.14, 95% CI 0.01 to 0.99)
Braham and Finch (2004) [44]	ARF, community-level, 23 senior and junior teams, 301 M	Clustered RCT, 1 season, 4 groups: headgear, mouthguard, headgear and mouth guard and control	Not reported		Unable to access effectiveness due to very low compliance with wearing headgear
Marshall et al. (2005) [45]	Rugby union, club level senior A, B, men, senior women, U/21, school boys. 240 M, 87 F	Prospective, cross-sectional, 1 season	Not reported	Orofacial, scalp, ears, concussion	Headgear reduced risk of scalp and ear injuries (RR = 0.59, 95% CI 0.19 to 1.86) Headgear did not reduce concussion risk
Kahanov et al. (2005) [46]	Rugby union, collegiate level from 8 universities, 131 M	Retrospective, cross-sectional, 49% headgear wearers, 51% non-wearers	Not reported	Concussion	Decreased portion of concussions for headgear wearers (24%) versus non-wearers (76%) and reduced severity

Table 4. (Continued)

Study (year)	Sport, level, participants	Study design	Headgear details	Head injuries	Significant findings ($p<0.05$)
Kemp et al. (2008) [47]	Rugby union, 13 professional clubs, 757 M	Prospective, cross-sectional, 3 seasons	Not reported	Concussion, head and facial fractures and lacerations	Headgear reduced incidence of concussion (2.0/1000 player-hr versus 4.6) and head injury in general
Delaney et al. (2008) [48]	Soccer, 12 to 17 yr olds, 1 club, 180 M, 98 F	Retrospective, cross-sectional, 1 season, 52 headgear wearers, 216 non-wearers	Headband configuration, no chin strap	Concussion, Head abrasions, laceration or contusions	Headgear reduced risk of concussion (RR = 0.38) and other head injuries
McIntosh et al. (2009) [49]	Rugby union, U13 to U20 M, 82 teams in season 1, 87 teams in season 2	Cluster RCT, 2 seasons, 1493 control, 1128 standard headgear wearers, 1474 modified headgear wearers	Standard headgear = 10 mm thick, 45 $kg.m^{-3}$ foam; modified headgear = 16 mm thick, 60 $kg.m^{-3}$ foam	Concussion and head injury	Headgear did not reduce the risk or severity of concussion or head injury
Hollis et al. (2009) [50]	Rugby union, nonprofessional, 26 clubs, 8 schools, 15 years and older, 3207 M	Prospective, cross-sectional, 1 to 3 seasons, 36% headgear wearers	Not reported	Concussion	Headgear reduced the risk of concussion (RR = 0.57, 95% CI 0.40-0.82)
Chalmers et al. (2012) [51]	Rugby union, amateur, 13 years and older, 704 M	Prospective, cross-sectional, 1 season, 1807 player exposures with headgear and 4223 without	Not reported	Any injury during the game	Headgear associated with increased risk of game injury (RR = 1.23, 95% CI 1.00-1.50)

CI = confidence interval; F = female; M = male; OR = odds ratio; RCT = randomised controlled trial; U = under; RR = rate ratio.

acknowledged that for this study a small number of concussions were registered, 7 players wearing headgear sustained concussion and 2 players without.

The other study [49] was a clustered by teams RCT that had two intervention arms, one group was provided with standard headgear and the other group was provided with modified headgear that was thicker and denser. This high-level study design did not find that headgear reduced the rate or severity of concussion. Low compliance was recognised as limitation with only 11% of total player-game exposures with the modified headgear but there was 46% exposure with the standard headgear; informal feedback from the players was that the modified headgear was too stiff and hence uncomfortable. There is no high-level evidence from prospective controlled trials that protective headgear can reduce the incidence of concussion but there is some evidence from cross-sectional studies that headgear can influence concussion risk and other head injury risks.

In these cross-sectional studies, headgear use was not randomised, the players self-selected whether to wear headgear and details of the headgear were not recorded. It was shown in some studies that headgear reduced the rate of superficial head injuries such lacerations and abrasions for a range of playing levels from school boy to professional [43, 45, 47] but this finding was not universal [43, 49]. There has been one retrospective, cross-sectional investigation with collegiate players [46] that reported a 70% reduction in concussion associated with headgear use. Of the three prospective cross-sectional studies that monitored concussion rate, two studies [47, 50] found that headgear decreased the incidence of concussion from 43 to 57% and the other study [45] did not detect a protective effect. Overall, it would appear that the effect of protective headgear on the incidence on concussion in rugby is inconclusive. As for the influence of headgear on concussion severity, two prospective studies did not find a difference in the average severity for wearers and non-wearers [47, 49] while the one retrospective study reported a reduction in the severity of symptoms from 4 days to 2 days [46]. The weight of the evidence at the moment suggests that headgear may not influence the severity of concussion.

One of the investigations [51] reported the effect of headgear on any game injury and found that headgear was associated with a 23% greater risk of injury. Since the categorisation of injuries to specific body parts was not provided, it is unknown what effect headgear had on head injury rate but this study does highlight an important issue, ‘risk compensation’ [52]. That is, athletes may develop a false sense of security when wearing headgear, reduce inhibition and engage in more physically aggressive play that may actual increase the risk of injury [30]. Further investigation is required on this issue [49] but none of the epidemiological studies to date on rugby, soccer or ARF have reported a significantly higher incidence of head injuries for athletes wearing headgear.

CONCLUSION

Head injuries and in particular concussion are a concern for participants in rugby, ARF and soccer. Non-mandatory soft-shell protective headgear are available and have been approved for use by the sport governing bodies as long as they do not pose an injury risk to any player. The general utilisation rate of headgear was 7 to 27 % in rugby and 2 to 8% in ARF; figures for soccer were not available possibly because of the recency of their adoption in the sport. The main reason for not wearing protective headgear was discomfort. Biomechanical evaluation of soccer headgear general found that impact during heading a soccer ball could be attenuated but this situation was not the main mechanism for head injury in that sport. Head contact with a firm object was more likely to produce injury and test scenarios simulating head to head contact found that soccer headgear could significantly attenuate impact. Laboratory assessment of ARF and rugby headgear generally found that the greater the headgear thickness, the greater the impact attenuation. The test results were very much dependant on whether a rigid or yielding headform and impact surface were used. Further research is required to fully establish a laboratory test protocol with biofidelic components, injury tolerance levels and impact characteristics that are representative of those that result in injury in the sport. Epidemiological data from high-level study designs revealed headgear did not decrease concussion or other head injury rate in teenage rugby players. No data were available for the effectiveness of headgear on head injury rate in ARF. There was low-to-moderate level evidence from prospective and retrospective cross-sectional studies that headgear could reduce concussion or other head injuries in soccer and rugby but some inconsistent results were also reported.

The weight of the evidence suggests that the non-mandatory headgear assessed so far cannot be relied on its own to significantly reduce head injury rates but should not be dismissed completely. Whether advancements in technology and materials significantly enhance the impact attenuation of protective headgear will need to await future research. It follows that the most effective way to reduce head injuries is to limit the possibility of head contact in the first instance. At the moment, headgear may be more effective as part of a multifactorial approach to injury reduction which would include education on safe sporting practises, skills training, strict adherence to rules, enforcement of penalties for dangerous play and thorough management of previous head injuries.

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