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REVIEW

Headguard use in combat sports: position statement of the Association of Ringside Physicians

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ABSTRACT
Headguard use is appropriate during some combat sports activities where the risks of injury to the face and ears are elevated. Headguards are highly effective in reducing the incidence of facial lacerations in studies of amateur boxers and are just as effective in other striking sports. They should be used in scenarios – especially sparring prior to competitions – where avoidance of laceration and subsequent exposure to potential blood-borne pathogens is important. Headguards are appropriate where avoidance of auricular injury is deemed important; limited data show a marked reduction in incidence of auricular injury in wrestlers wearing headguards.

Headguards should not be relied upon to reduce the risk of concussion or other traumatic brain injury. They have not been shown to prevent these types of injuries in combat sports or other sports, and human studies on the effect of headguards on concussive injury are lacking. While biomechanical studies suggest they reduce linear and rotational acceleration of the cranium, changes in athlete behavior to more risk-taking when wearing headguards may offset any risk reduction. In the absence of high-quality studies on headguard use, the Association of Ringside Physicians recommends that further research be conducted to clarify the role of headguards in all combat sports, at all ages of participation. Furthermore, in the absence of data on gender differences, policies should be standardized for men and women.

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Preamble: development of this statement

This position statement expresses a collaborative effort among the Association of Ringside Physicians (ARP) Board of Directors, Emeritus Board, and subject matter experts. An extensive literature search including but not restricted to MEDLINE, Cochrane Review, and non-indexed peer-reviewed articles published in online medical journals was performed using search terms of boxing, mixed martial arts, judo, taekwondo, wrestling, karate, combat sports, headguard, headgear, head injury, concussion, facial injury, craniofacial injury, and closed head injury.

History of sport-specific practices and rules regarding headguards

Headguards (also known as headgear) used in combat sports are padded helmets or protective devices, made primarily of soft, elastic materials, that are intended to absorb and distribute energy across a larger surface area. Headguards generally do not encompass the entire non-facial skull. Some have non-padded straps across the top of the head, and some are limited to protective plates over the ears. Headguards vary in the amount and exact placement of facial protection, but all leave the eyes, nose, and mouth unprotected to provide unobstructed vision and respiration (Figure 1).

Combat sports are a heterogeneous group with some forms focused primarily on using grappling techniques, various striking techniques, or a mixture. Athletes in boxing (a punching-based sport), taekwondo (a kicking-based sport), kickboxing (where punching and kicking are equally important), muay thai (which allows punching, kicking, and knee/elbow strikes), karate (kicking favored over punching), and mixed martial arts (MMA) have long utilized headguards during sparring. Blows to the head are considered legal and effective for scoring and winning in each of these disciplines. Grappling predominant combat sports such as wrestling, judo, and jiu-jitsu have not traditionally emphasized headguard use; that being said, in American interscholastic wrestling headguards are worn solely to protect the ears from auricular hematoma. Additionally, athletes in grappling sports may temporarily wear headguards with face shields to protect a healing facial injury.

Common perceptions among athletes and coaches are that headguards protect against facial cuts, auricular hematomas, and cerebral concussion during sparring. Sparring (fighting with a live opponent to simulate competition) can be an important training technique for fight preparation. This is especially true for professional fighters, for whom a training 'camp' may involve intense sparring matches with opponents carefully chosen to resemble an

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Figure 1. Representative headguards for specific combat sports.

upcoming opponent. Injury prevention is especially important in athletes with upcoming fights since sparring injuries could lead to fight cancellation or delay for several weeks. Therefore, headguards worn in sparring are often significantly larger and provide more facial protection than those used in competition.

Each sport has its own governing body from which rules and standards of competition are created. Amateur kickboxing and taekwondo governing bodies require headguards during competition. Amateur boxing governing bodies require headguards for all youth and women athletes but prohibit them for elite men competing in national and international competitions. Prior to 1984 headguards were not used in amateur boxing competitions. In response to an outcry from organizations including the American Medical Association for more safety measures in boxing, headguards were mandated for amateur boxing at the 1984 Los Angeles Olympics, despite a lack of evidence that headguards prevented neurologic injury [1]. In 2013, the International Boxing Association (IBA, formerly AIBA), which regulates elite amateur boxing, banned the use of headguards for elite men during competitions. This reasoning stemmed from an assertion that headguards were not protective against cerebral concussion and may even be harmful. Furthermore, there were concerns that headguards provided a false sense of security, thus encouraging athletes to take more risks, or to lead with their head. This decision was also made with the intent to ease the transition of elite amateur boxers into professional boxing, where headguards are not worn, and to satisfy both the media and spectators, who desired to see boxers' faces during televised competition [2]. The 2016 Olympic Games in Rio de Janeiro were the first since 1984 in which headguards were banned for male boxers, but they were still required for female boxers despite the absence of a medical justification for the disparity.

Epidemiology of head injury in combat sports

Each sport has distinct injury patterns due to differences in rules, types of strikes, legal targets, point scoring, training patterns, and required protective equipment. One cross-sectional study showed that striking-predominant combat sports resulted in higher head and facial injuries. These included facial abrasion, facial fracture, periorbital injury, and concussion [3]. A systematic review of studies also showed that craniofacial injuries are most often associated with striking sports [4]. Available data currently show that the pattern of craniofacial injury is similar in both MMA and professional boxing, with the most injured anatomic region being the head [5]. Key studies on craniofacial injury epidemiology in combat sports are summarized in Table 1 [6–14].

In amateur boxing, the most injured body regions are the head and face (mostly contusions) and upper the limb muscle (mostly strains), according to a systematic review that included 17 studies [15]. The proportion of head injuries varies from 10% to 70% of all injuries depending on the study design [2]. One prospective cohort study of 33 amateur and 14 professional boxers from Australia reported that 71% of injuries were craniofacial, with concussion the most common injury (33% of

Table 1. Summary of studies on craniofacial injuries across combat sports.

				Injury Type %				
Study	Combat Sport	Design	N	TBI/ Concussion	Lacerations/ Abrasions/ Contusion	Fracture	Other	Findings
Fares et al 2020 [1]	MMA	Epidemiological study: Ringside physician reports of the Ultimate Fighting Championship (UFC) fights between 2016 and 2019 (inclusive) were screened. Data were extracted from the Nevada State Athletic Commission (NSAC) database. Play-by-play video analysis was also conducted.	816	45%	35%	15%	5%	Brain was the most common injury location and TBI being the most common. Head injuries were significantly impacted by weight class and finish i.e. KO vs submission.
Wolfe E et al 2021 [2]	Boxing	The National Electronic Injury Surveillance System database was searched for boxing-related craniofacial injuries from the last 10 years (2010–2019).	732	25%	47%	23%	5%	High incidence of boxing-related craniofacial injuries such as concussions and lacerations incurred in young adults (19–34 years) and adolescents (12–18 years).
Karpman et al 2016 [3]	Boxing MMA	Consecutive Case Series: Data from post-fight medical examinations on all bouts in Edmonton, Canada, between 2000 and 2013.	550 1181	10% 8%	53% 64%	4% 5%	7% 5%	Overall injury incidence in MMA appears higher than for boxers however boxers demonstrate more head trauma/concussion.
McClain et al 2014 [4]	MMA	Correlational and multivariate analyses were conducted on cross-sectional data to examine injuries sustained during MMA amateur and professional bouts in Kansas and Missouri. One physician completed the exams.	1422	22%	38%	17%	24%	MMA bouts were almost 3 times more likely to be ended by KO/TKOs than submissions, decisions, or disqualifications. However MMA is still below the KO rate in boxing.
Hojjat et al 2016 [5]	Boxing MA Wrestling	The National Electronic Injury Surveillance System (NEISS) was evaluated for facial injuries from wrestling, boxing, and martial arts leading to ED visits from 2008 to 2013. There were 1143 entries extrapolating to an estimated 42 395 ED visits from 2008 to 2013.	343 389 411	- - -	55% 69% 70%	37% 24% 19%	2% 2% 6%	Boxers demonstrated the highest proportion of facial fractures.
Arriaza et al 2005 [6]	Karate	Prospective recording of injuries resulting from 2,837 matches in three consecutive WKC, the 13th WKC in Sun City (South Africa 1996), the 14th WKC in Río (Brazil 1998) and the 15th WKC in Munich (Germany 2000). Multiple ringside physicians evaluated/examined competitors.	891	4%	69%	3%	16% Epistaxis	Competitors sustained the most injury to their face 72.5% and head 11.6%. Contusions, bruises, sprains and strains showed to be the most common injuries. Severe injuries in competitive karate are found to be rare compared to taekwondo and amateur boxing.
Schlüter-Brust et al 2011 [7]	Taekwondo recreational Taekwondo professional	Epidemiologic study on the variety of types of injury in professional and amateur Taekwondo athletes; analyzed the injury data using a 7-page questionnaire from a total of 356 Taekwondo athletes who were randomly selected.	84 272	4% 23%	30% 39%	5% mandible 3% mandible	- -	Total of 2 164 injuries; most were contusions and sprains in the lower extremities. Professional Taekwondo athletes have an increased risk of injury in comparison to recreational athletes. Concussions amounted to 16.2% of the injuries and 10% were lacerations of the lips and contusions of the nose.

(*Continued*)

Table 1. (Continued).

Siewe et al 2015 [8]	Boxing	Prospective epidemiological study. Data was collected by questionnaire once a month for one year. From October 2012 to September 2013, 44 boxers (42 male, 2 female) were asked to report their injuries. A total of 192 injuries were recorded, 133 of which resulted in interruption of training or competition. Only active, competitive boxers were recruited.	192	4%	32%	1% nasal	9%	Boxing shows a high injury rate that is comparable with other contact sports. Injury frequency was very significantly correlated with the number of bouts per year. Boxers who had more than 3 bouts per year sustained more injuries than those with less.
Zazryn et al 2003 [9]	Boxing professional	Professional boxing fight outcomes and injuries sustained during competition, from August 1985 to August 2001, were obtained from the Victorian Professional Boxing and Combat Sports Board. 427 boxing fight participations recorded in the database. Of these, 94 were associated with 107 injuries	107	16%	74%	5%	5%	Injury rate of 250.6 injuries per 1000 fight participations. The most commonly injured body region was the head/neck/face (89.8%), followed by the upper extremities (7.4%). Specifically, injuries to the eye region (45.8%) and concussion (15.9%) were the most common.

total), followed by lacerations (29%), and fractures (19%) [16]. The eyebrow and nose were the other common sites of injury. Most injuries to the eye region were lacerations, although conjunctival, corneal, and retinal lesions were also reported. Data from two studies on boxing injuries presenting to emergency departments – which are biased toward more severe conditions – show that laceration, concussion, contusion/abrasion, fracture, and eye trauma are the most common craniofacial injuries needing emergency care [7,17].

Most head injury deaths in boxing are associated with traumatic brain injury from blows to the head [18]. Fatalities from head injury occur at an average rate of one per 5,000 professional boxing bouts in the modern era, and just over half of boxing deaths occur in amateurs [18]. About 75% of head injury fatalities are from subdural hematoma, followed by diffuse axonal injury, epidural hematoma, intracerebral hemorrhage, and cerebral contusion [19]. There was a significant decline in boxing mortality rate after 1983, thought to be due to increased medical oversight and stricter safety guidelines [19]. In Australia, boxing fatalities declined from the 1930s until the 1980s, without any improvement after more boxing regulations were introduced in the mid-1970's [20]. Data for fatality rates in mixed martial arts are currently unavailable [21].

Controversy exists on the relationship between combat sports and chronic traumatic brain injury. In 2007, a methodologically weak systematic review of literature concluded that the quality of evidence supporting an association between CTE and professional boxing was poor [22]. However, a preponderance of more modern evidence suggests a causative link between repetitive head impacts (from any cause) and chronic traumatic encephalopathy [23].

In MMA, there is infrequent use of headguards in competition, and the gloves (which leave the fingers exposed) are smaller and lighter than gloves used in boxing. Head trauma constitutes between 58% and 78% of all injuries in MMA, according to a systematic review of studies [24]. One retrospective study showed that the most common reason for MMA bouts ending early was closed head trauma; the concussion rate was 48 per 1,000 fight exposures [25]. Risk factors for head trauma in MMA include higher weight class, older age, and bouts ending in knockout or technical knockout [6]. Although MMA allows all techniques of martial arts, including grappling, throws, submissions, and strikes, video analysis identified that all knockouts were the result of direct impact to the head, most frequently a strike to the mandibular region [26].

Karate and taekwondo allow strikes to the head, but their rules enforce more control over those techniques. In karate, which does not require headguards, the most injured body region is the head and neck, but control rules result in a lower level of craniofacial injury severity (mostly contusions and lacerations) [27]. In taekwondo, competitors are required to wear headguards and gloves. A meta-analysis of prospective studies found that 24% of injuries in taekwondo involve the head and neck. Most were contusions, and only 5.4% were concussions [28]. Karate and taekwondo both had lower rates of concussion injuries than in boxing [29].

In contrast, grappling-predominant disciplines such as jiu-jitsu, judo, and wrestling have lower craniofacial injury rates than striking sports and higher rates of joint injuries such as shoulder, elbow, knee, and fingers [4,30,31]. None of these sports require the use of headguards at the elite competitive level, though American high school and collegiate wrestling require use of headguards that cover the ears. In American collegiate wrestling, head and face injuries comprised 13% of all injuries [31], and face/ear/eye/mouth injuries comprised 9.9% in youth ages 12–17 [32]. One retrospective self-report study showed that among 571 collegiate wrestlers, those who wore headguards were much less likely to develop auricular hematomas than those not wearing them (26% versus 52%) [33]. This data supports the common notion that headguards in wrestling provide a significant reduction in the incidence of auricular injury.

Biomechanics of striking with and without headguards

While amateur boxing requires that headguards meet weight dimensions (<450 g), governing bodies do not require those headguards to meet performance standards, such as those outlined by the American Society of Testing and Materials (ASTM) [34–36]. As such, the performance of these headguards is widely variable. In a study of two common boxing headguards, there was a 32% to 40% difference found between mean peak linear acceleration resulting from lateral and frontal impacts [37]. Another study that looked at two IBA headguards and two World Taekwondo (WT) federation-approved headguards found that none met ASTM standards to attenuate linear acceleration below a threshold of 150 g [38]. While these results leave the combat sport community questioning how effective headguards are, other studies suggest that headguards can meaningfully attenuate linear and angular acceleration. In a study that compared IBA-approved headguards to non-headguards, significant reductions in mean peak linear and angular acceleration were found with headguards. Mean peak linear acceleration reached 85 g with headguards relative to 130 g without. Likewise, the angular acceleration was 5,200–5,600 rad/sec^2 without headguard and almost halved with headguards. A similar reduction was seen when the blow was at an oblique angle (45 and 60 degrees), with a more significant reduction in these parameters at a higher striking velocity [35].

Materials properties have been poorly studied in combat sport headguards, yet it is widely accepted that variables such as foam thickness, composition, and contact friction can be altered to reduce risk of injury to the head and neck [39–45]. For example, one study found that the best performing headguards were those that were the heaviest (0.53 kg) or the thickest (37 mm), whereas the lightest and thinnest performed the worst. The best performing headguard resulted in a reduction of linear acceleration from 456 g to 48 g relative to non-headguard. Foam density was less significant, such that when two headguards with the same density were compared side by side, the thicker one was able to reduce head acceleration 7–8× more effectively with only a 0.09 kg increase in overall mass [37]. The same study found that after exposure to repeated anvil drops, performance declined in all IBA headguards. However, the deterioration of the foam was less rapid when the headguards were struck with boxing gloves relative to bare fists, which was thought to be due to less foam deformation when struck by gloves [37,43,46]. Nonetheless, any protective benefit provided by headguards can be expected to diminish with repeated blows, and the current literature offers little guidance as to the interval at which headguards should be replaced.

There is a paucity of studies that quantify variables to be considered when designing and determining whether a headguard can meaningfully protect the combat sport athlete from both external and internal head injury. Headguards should be tailored to the sport, as it has been found that higher peak angular acceleration is seen in MMA than boxing. Boxers are more likely to be struck in the front of the head and MMA athletes closer to the back [3], which is an important consideration when determining where headguards should be more heavily padded. Additional considerations for padding placement come from a study that found that linear and angular acceleration for both frontal and top of head impacts were lower than lateral or posterior impacts [47].

Questions remain whether results from studies conducted in labs should be used to guide decisions regarding the use of headguards in combat sports. This is in part because studies have shown that the forces of punches during competition only reach half that produced by maximal effort punches produced in the lab setting. Moreover, most punches during competition fall below the 25% probability threshold for causing head injury [47–50]. However, subconcussive head impacts have long been a concern in all contact and collision sports since accumulation of these lower energy blows may still result in neurological impairment. Even with headguards, boxers demonstrate some mild cognitive impairment from repeated subconcussive head impacts, when measured with computerized neurocognitive testing [45]. More problematic is that many of the lab studies use equations to predict brain trauma and skull fracture that are based on linear parameters, yet angular acceleration is thought to be a more significant contributor to brain injury, especially when accumulated over time [50–54]. Several studies have found that angular acceleration and linear acceleration tend to be higher with lateral head impacts, and it is these blows that are more likely to result in brain injury [47,55,56].

The capacity to achieve high rotational and linear acceleration, momentum, and overall force has been found to have a linear correlation with increasing weight class and skill due to a greater effective mass of the fist [54,57–60]. The hook punch was shown in a biomechanical study to be most likely to create forces capable of causing a traumatic brain injury by knockout. The authors postulated that this is due to greater angular acceleration resulting in more strain on the brain parenchyma [61]. The turning kick (round or roundhouse kick) frequently used in taekwondo, kickboxing, muay Thai, and MMA has been shown to produce linear head acceleration of 60–217 g when delivered by taekwondo athletes to an instrumented crash dummy head fitted with a standard taekwondo headguard. This level of acceleration has been determined to produce a Head Injury Criterion (HIC) of 128–1,608, with HIC of 1,000 or higher suggested as being in the life-threatening range [62]. Gender may also affect

Table 2. Summary of studies on results of bout stoppage and cut incidence with and without headguards.

	Bianco et al 2013		Loosemore et al 2017		Davis et al 2018	
	Headguard	Without Headguard	Headguard	Without Headguard	Headguard	Without Headguard
RSCI	0.6%	2.0%				
RSCH	4.9%	1.3%	~42 pth*	14.91 pth		
RSC	13.0%	9.7%				
KO	3.8%	6.3%			0.0%	0.01%^
Any stoppage	21.7%	17.3%			1.7%	4.2%
Cuts			~36 pth	320.65 pth		

Note: RSCI: Referee Stops Contest, Injury. RSCH: Referee Stops Contest, Headblows. RSC: Referee Stops Contest. KO: Knockout.
*pth = per thousand hours of boxing.
^Statistical significance not stated.

striking impact force, but studies show mixed results. One study of boxers showed higher peak linear acceleration by males relative to females [47], but another showed comparable punch force magnitude in men and women [3].

Headguard use and athlete behavior

There has long been speculation on how the use of headguards in combat sports results in changes in athlete behavior. In American football, it is widely accepted that the use of helmets resulted in a change in behavior, notably by using the helmet as a tackling 'weapon.' While helmets protect football players from skull fractures and intracranial hemorrhage, they may have led to increased rates of concussion because of changes in tackling techniques. In a similar vein, some have speculated that headguard use in boxing can have unintended consequences. Headguards may impart a sense of safety from head blows, resulting in boxers leading with their heads or absorbing more blows through their guard. In addition, headguards may impair peripheral vision, leading to more lateral blows landing without adequate defense. This rationale, in part, led to the 2013 IBA rule change prohibiting headguards in elite male international competition.

Two subsequent retrospective observational studies provide evidence supporting the notion that removing headguards in elite amateur boxing resulted in behavioral changes that resulted in more avoidance of head blows. Davis et al. [63] studied the changes in elite male international amateur boxing after the 2013 rule change by comparing bouts in the 2012 London Olympics with those in the 2015 Doha World Championships. Video review of 29 bouts with headguards and 50 bouts without headguards was performed by a single evaluator. Punch accuracy (i.e. landing rate) was significantly lower without headguards. Defensive movements and overall activity rate were higher without headguards. Single punches (as opposed to combinations) were more frequent, and punches with the rear hand were less frequent, without headguards. Punches that landed and hook punches (coming from the side of the head) were lower without headguards. The ratio of head to body punches increased from 5:1 to 8:1 after removing headguards but was offset by a decrease in accuracy. The authors suggest that removing headguards led boxers to use more defensive movements and more foot movement and to use a more 'in and out' defensive style with less 'in-close' technique.

Davis et al. [64], in a separate paper also analyzed the activity profiles of elite male amateur boxers after the 2013 headguard rule change using video review. They found that the winners had a higher number of straight punches and increased accuracy over subsequent rounds. They noted that a winning strategy in elite male international boxing without headguards had become more long-range and defensive, in contrast to the short-range boxing with more hook punches that characterized boxing with headguards.

Headguard rule changes and craniofacial injury

Headguards increase the diameter and surface area of the head, which can lead to increased rotational force from blows, as discussed above. In addition, padding around the eyes may limit vision [1], impairing proper defense for blows coming from the sides of the head. Studies comparing the epidemiology of craniofacial injury in combat sports with and without headguards are few and are limited to amateur boxing. Table 2 summarizes the results of three studies. A systematic analysis of the literature in 2021—including these studies – concluded that while headguards do protect against lacerations, it is not known if headguards protect against concussion and other traumatic brain injuries in elite and youth Olympic boxing [2].

A prospective study of injuries in combat sports (boxing, taekwondo, wrestling, and judo) in three Olympic Games from 2008 to 2016 showed that the rule that removed headguards resulted in a threefold increase in injury risk in boxers. The types and severity of injuries sustained were not specified [65].

A retrospective study [66] of 29,357 bouts in 269 national and international amateur boxing events between 1952 and 2011 examined rates of injury and bout stoppage with and without various rule changes such as headguards, round number and length, standing count, and scoring method. Data included rates of Knockout (KO), Referee Stops Contest (RSC), Referee Stops Contest for Head blows (RSCH), and Referee Stops Contest for Injury (RSCI, such as for cut, fracture, or dislocation). Comparing the period of 1952–1984 when headguards were not used, with the period of 1984–1997 when headguards were mandated, there were statistically significant reductions in RSCI (2.04% to 0.60%) and KO (6.31% to 3.78%) after the introduction of headguards. However, the incidence of RSCH increased from 1.31% to 4.92% after the headguard mandate, and the incidence of RSC increased from 9.71% to 13.05%. The incidence of any referee stoppage (RSC, RSCH, and KO in sum) increased after mandatory headguard use from 17.33% to 21.75%. Comparing the smaller cohorts from 1964–1984 (after the standing-8 rule began) to the cohort after 1984 showed an insignificant change in incidence of contest stoppage. The authors hypothesize that boxers with headguards felt more protected and exposed themselves to blows that they may have avoided without headguards. They also qualify their findings with the fact that new rules in the headguard era allowed referees to stop bouts earlier. The threshold for referee stoppage due to head blows may have been lower in later years due to some high-profile deaths in professional boxing around that time and a greater understanding of the risks imposed by head trauma [67].

A cross-sectional observational study [1] compared amateur male boxing bouts in the 2009 and 2011 world championships conducted with headguards to the 2013 world championships without headguards. A potentially confounding variable of different bout format (five rounds of 3 minutes each in 2009/2011 versus three rounds of 3 minutes each in 2013) was corrected by using the number of rounds as the denominator. The data showed a 43% lower incidence of RSCH (head blow stoppage) without headguards (RR = 0.57) compared to bouts with headguards. There was a 430% higher incidence of cuts (RR = 5.30) without headguards. While the authors posited that RSCH is a surrogate marker for concussion, the rate of actual medical diagnosis of concussion was not cited in the study, and this assumption is fraught with inaccuracy. Referees have less training in concussion than ringside physicians and may have difficulty identifying concussions that do not involve alteration of consciousness [68].

Another retrospective study [63] compared the incidence of injury and bout stoppage male boxers with headguards in the 2012 Olympics (239 bouts) with that in the 2015 World Championships without headguards (238 bouts). In bouts with headguards 1.7% ended by referee stoppage (no further data on reasons for stoppage), compared with 4.2% without headguards. However, the statistical significance of this difference was not quantified, and the difference was described as ‘equivocal’ because the reasons for referee stoppage were not ascertained, and there was no data on actual injuries, if any. It was not specified if referee stoppages were for head blows or other reasons such as body blows. There were no knockouts in 2012 with headguards and two knockouts in 2015 without headguards (0.008%); statistical significance was not quantified.

Discussion

Setting policy and making decisions on headguard use in combat sports should optimally be based on high-quality empirical data showing the risks and benefits of using or not using them. Unfortunately, the amount of research on this topic is extremely limited. Epidemiological studies show that combat sports carry a significant risk of craniofacial injury. Biomechanical studies suggest a possible protective effect of headguards, but their findings have limited to no application in real-world practice. Available studies comparing injuries during sports with and without headguards are limited in number, poor in quality, and have confounding variables that limit their usefulness.

Lacerations

The common belief that headguards reduce the incidence of facial lacerations [67] is supported by a large retrospective cohort study showing a magnitude of reduction of about 90% [1]. While the risk of facial laceration depends partly on combatant behavior (i.e. using the head as a weapon), it is reasonable to state that headguards in striking sports have utility in preventing lacerations. This may be particularly desirable in some scenarios such as sparring before competitions, tournament style events in which lacerations could disqualify athletes from progressing through the brackets, or when there is a desire on the part of sanctioning bodies or athletes to avoid the cost and medical consequences of lacerations.

Auricular injury

The common notion that headguards reduce the incidence of auricular injury (hematoma) is supported by only one self-report retrospective study [33], but the magnitude of reduction (about 50%) solidly supports the notion. Wrestling and jiu-jitsu are the disciplines most likely to have athletes who use these devices. However, the prevalence of use is low, and inconsistent compliance limits effectiveness. There also exists a culture among these athletes that the resulting ear deformities (cauliflower ear) are a ‘badge of honor,’ and something expected, if not desired. Education of these athletes on the potential medical consequences of auricular hematoma (including potential obstructive hearing loss from cauliflower ear involving the auditory canal) may promote increased prevalence of headguard use and reduce the risk of auricular injury.

Traumatic brain injury

Loss of consciousness (LOC) has been found to be associated with delayed recovery in sport, suggesting that it may indicate more severe injury [46,69,70]. Concussion occurring without LOC – even subconcussive blows – can also have short- and medium-term deleterious effects on the brain, especially repeated injuries. The repetitive head impacts (RHI – both concussive and subconcussive) produced in boxing and other combat sports have not been proven by prospective double-blind studies to cause chronic traumatic encephalopathy (CTE), but they remain a likely risk factor. Though one poorly designed systematic review in 2007 of studies in professional boxers did not find support for an association between RHI and CTE in professional boxing [22], a preponderance of more recent evidence suggests a causative link between RHI and CTE. The US Centers for Disease Control and Prevention and the US National Institute of Neurological Disorders and Stroke have stated that CTE is caused, at least in part, by repeated traumatic brain injuries, including concussions and subconcussive impacts [71,72]. Most recently, a compelling argument for CTE causation by RHI was made using the nine Bradford Hill criteria for causation that were used in cigarette smoking and lung cancer causation [23].

Minimizing forces involved in head impacts in combat sports would seem to be desirable to support the goal of preventing concussion and the cumulative effects of subconcussive blows. While biomechanical lab studies show that headguards can reduce the linear and angular acceleration induced by blows to the head, there are no studies in combat sports showing a preventive effect of headguards on concussion or the long-term effects of repetitive head impacts. Therefore, in the absence of good research, no conclusions can be made on the value of headguards in this type of injury. Systematic reviews and meta-analyses show that headguards and helmets do not reduce the incidence of concussion in team sports either [73–75]. While helmets in American football are widely believed to prevent skull fractures, there are no empirical data available yet to support or refute this effect by headguards in combat sports. Optimally, high quality, prospective, randomized studies with accurate data collection and analysis are required before conclusive statements can be made regarding the effect of headguards on concussive brain injury in striking sports.

The move away from headguards in elite male amateur boxing has been controversial for many reasons. Support for the removal of headguards comes from the as-yet unproven notion that athletes are at increased risk of injury due to an increased surface area of the head and limitation of peripheral vision. Headguard removal has also been shown to result in a shift in athlete behavior to a more defensive strategy. However, the contradictory nature of eliminating headguards in elite men but not in elite women is concerning. Perceptions within the non-medical community of combat sports indicate a reluctance to eliminate headguards in competition. An online poll of the Canadian amateur boxing community 2 years after the IBA headguard ban for elite male amateur boxing indicated that 71.5% of respondents believed headguards should always be mandatory in amateur competition because they are perceived to protect from concussive injury [67].

Available studies to date on the effect of headguards are limited to elite amateur boxing and are inconclusive regarding injury, since they all used administrative boxing endpoints of referee stoppage as numerators, not specific injuries. The two largest studies [1,66] showed that headguards were associated with higher incidences of stoppages for head blows, but one of them [66] and one smaller study [64] showed that headguards were associated with lower rates of Knockout (boxer unable to continue). These data could be explained by two theories: first, that boxers behave differently when not wearing headguards to avoid getting punched as much, thus reducing the number of subconcussive blows sustained. Second, when a head blow does connect, headguards may have a protective effect in reducing forces that could cause a boxer to be unable to continue. Unfortunately, none of these studies have data on the effect of headguards on actual injuries (other than laceration).

Headguards and athlete behavior

At least one study [64] in combat sports supports the notion that behavioral change does occur when there is a perception that the head is protected or not protected. The authors noted decreased risk taking and greater use of defensive strategy in elite male amateur boxers after removal of headguards. This can confound the overall effect of headguards on injury prevention. Indeed, studies in other sports have documented increased risk-taking in skiers, snowboarders [76] and cyclists [77] who wear helmets. The widely recognized unanticipated effect of helmets in American football being used as a tackling weapon further supports this notion.

Future research

This discussion should make it apparent that the dearth of research on headguards in combat sports leaves medical professionals, regulating bodies, coaches, and athletes with insufficient information to know their best uses. Suggestions for future research include randomized studies on the use of headguards in not just boxing but other striking sports. Endpoints must include injury outcomes, in addition to administrative competition endpoints such as RSCH, RSCI, Knockout, etc. Studies that examine behavioral changes should include men and women, and athletes of varying age, to determine if certain ages and/or sexes are more or less likely to change behavior, and how this might affect injury risk. Studies of various headguard designs should be conducted with humans, with quantification of linear and angular acceleration, forces absorbed, and neurological outcomes.

Practice Implications

Based on available literature, the Association of Ringside Physicians recommends use of facial protection headguards when prevention of facial lacerations is desirable. This is especially important in sparring prior to competitions or in tournament style competitions with multiple bouts in which a laceration could preclude further competition. Headguards with ear protection should be used in grappling sports (e.g. wrestling, jiu jitsu) when avoidance of auricular injury is deemed important or to protect a healing auricular injury. Headguards should not be relied upon to reduce the risk of concussion or other traumatic brain injury. The ARP recommends that headguard rules by sport governing bodies (e.g. IBA) be equalized for men and women.

Qualifying statement

These guidelines are recommendations to assist ringside physicians, combat sports athletes, coaches, promoters, sanctioning bodies, governmental bodies, and others in making decisions and setting policy. These recommendations may be adopted, modified, or rejected according to clinical needs and constraints and are not intended to replace local commission laws, regulations, or policies already in place. In addition, the guidelines developed by the ARP are not intended as standards or absolute requirements, and their use cannot guarantee any specific outcome. Guidelines are subject to revision as warranted by the evolution of medical knowledge, technology, and practice. They provide the basic recommendations that are supported by synthesis and analysis of the current literature, expert and practitioner opinion, commentary, and clinical feasibility.

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References

1. Loosemore MP, Butler CF, Khadri A, et al. Use of headguards in AIBA boxing tournaments: a cross-sectional observational study. Clin J Sport Med. 2017;27(1):86–88. doi: 10.1097/JSM.0000000000000322
2. Tjønndal A, Haudenhuyse R, de Geus B, et al. Concussions, cuts, and cracked bones: a systematic literature review on protective headgear and head injury prevention in Olympic boxing. Eur J Sport Sci. 2022;22 (3):447–459. doi: 10.1080/17461391.2021.1872711
3. Jansen AE, McGrath M, Samorezov S, et al. Characterizing head impact exposure in men and women during boxing and mixed martial arts. Orthop J Sports Med. 2021;9(12):23259671211059815. doi: 10.1177/23259671211059815
4. Pieter W. Martial arts injuries. Med Sport Sci. 2005;48:59–73.
5. Lystad RP, Gregory K, Wilson J. The epidemiology of injuries in mixed martial arts: a systematic review and meta-analysis. Orthop J Sports Med. 2014;2(1):2325967113518492. doi: 10.1177/2325967113518492
6. Fares MY, Salhab HA, Fares J, et al. Craniofacial and traumatic brain injuries in mixed martial arts. Phys Sportsmed. 2021;49(4):420–428. doi: 10.1080/00913847.2020.1847623
7. Wolfe EM, Pierrot RG, Slavin BR, et al. Rolling with the punches: a national electronic injury surveillance system database study of craniofacial injuries in boxing. J Craniofac Surg. 2021;32 (4):1576–1580. doi: 10.1097/SCS.0000000000007640
8. Karpman S, Reid P, Phillips L. Phillips L et al.Combative sports injuries. Clin J Sport Med. 2016;26(4):332–334. doi: 10.1097/JSM.0000000000000235
9. McClain R, Wassermen J, Mayfield C, et al. Injury profile of mixed martial arts competitors. Clin J Sport Med. 2014;24(6):497–501. doi: 10.1097/JSM.0000000000000078
10. Hojjat H, Svider PF, Lin H-S, et al. Adding injury to insult: a national analysis of combat sport–related facial injury. Ann Otol Rhinol Laryngol. 2016;125(8):652–659. doi: 10.1177/0003489416644617
11. Arriaza R, Leyes M. Injury profile in competitive karate: prospective analysis of three consecutive world karate championships. Knee Surg Sports Traumatol Arthrosc. 2005;13(7):603–607. doi: 10.1007/s00167-004-0593-6
12. Schlüter-Brust K, Leistenschneider P, Dargel J, et al. Acute injuries in taekwondo. Int J Sports Med. 2011;32(8):629–634. doi: 10.1055/s-0031-1275302
13. Siewe J, Rudat J, Zarghooni K, et al. Injuries in competitive boxing. A prospective study. Int J Sports Med. 2015;36(3):249–253. doi: 10.1055/s-0034-1387764
14. Zazryn TR, Finch CF, McCrory P. A 16-year study of injuries to professional boxers in the state of Victoria, Australia. Br J Sports Med. 2003;37(4):321–324. doi: 10.1136/bjsm.37.4.321
15. Alevras AJ, Fuller JT, Mitchell R, et al. Epidemiology of injuries in amateur boxing: a systematic review and meta-analysis. J Sci Med Sport. 2022;25(12):995–1001. doi: 10.1016/j.jsams.2022.09.165
16. Zazryn T, Cameron P, McCrory P. A prospective cohort study of injury in amateur and professional boxing. Br J Sports Med. 2006;40 (8):670–674. doi: 10.1136/bjsm.2006.025924
17. Public Health Agency of Canada, Health Surveillance and epidemiology division of injuries associated with formal boxing. Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) Database,1990–2007 (cumulative to December 2008), ages 5 years and older (273 records).Available from https://www.canada.ca/en/public-health/services/injury-prevention/health-surveillance-epidemiology-division.html
18. Neidecker J, Martin J. Mortality resulting from head injury in professional boxing revisited: fatalities from 2000-2019. J Combat Sports Med. 2022;4S:38.
19. Baird LC, Newman CB, Volk H, et al. Mortality resulting from head injury in professional boxing. Neurosurgery. 2010;67(5):1444–1450. doi: 10.1227/NEU.0b013e3181e5e2cd
20. Alevras AJ, Fuller JT, Mitchell R, et al. Boxing-related fatalities in Australia: a retrospective analysis of news media reports. J Sci Med Sport. 2022;25(1):25–30. doi: 10.1016/j.jsams.2021.08.002
21. Thomas RE, Thomas BC. Systematic review of injuries in mixed martial arts. Phys Sportsmed. 2018;46(2):155–167. doi: 10.1080/00913847.2018.1430451
22. Loosemore M, Knowles CH, Whyte GP. Amateur boxing and risk of chronic traumatic brain injury: systematic review of observational studies. BMJ. 2007;335(7624):809. doi: 10.1136/bmj.39342.690220.55
23. Nowinski CJ, Bureau SC, Buckland ME, et al. Applying the Bradford Hill Criteria for causation to repetitive head impacts and chronic traumatic encephalopathy. Front Neurol. 2022 Jul 22;13:938163. doi: 10.3389/fneur.2022.938163
24. Schlegel P, Novotny M, Valis M, et al. Head injury in mixed martial arts: a review of epidemiology, affected brain structures and risks of cognitive decline. Phys Sportsmed. 2021;49(4):371–380. doi: 10.1080/00913847.2021.1885966
25. Buse GJ. No holds barred sport fighting: a 10-year review of mixed martial arts competition. Br J Sports Med. 2006;40(2):169–172. doi: 10.1136/bjsm.2005.021295
26. Hutchison MG, Lawrence DW, Cusimano MD, et al. Head trauma in mixed martial arts. Am J Sports Med. 2014;42(6):1352–1358. doi: 10.1177/0363546514526151
27. Lystad RP, Augustovičová D, Harris G, et al. Epidemiology of injuries in Olympic-style karate competitions: systematic review and meta-analysis. Br J Sports Med. 2020;54(16):976–983. doi: 10.1136/bjsports-2020-101990
28. Lystad RP, Pollard H, Graham PL. Epidemiology of injuries in competition taekwondo: a meta-analysis of observational studies. J Sci Med Sport. 2009;12(6):614–621. doi: 10.1016/j.jsams.2008.09.013
29. Zazryn TR, McCrory PR, Cameron PA. Neurologic injuries in boxing and other combat sports. Phys Med Rehabil Clin N Am. 2009;20 (1):227–239. doi: 10.1016/j.pmr.2008.10.004
30. Pococco E, Ruedl G, Stankovic N, et al. Injuries in judo: a systematic literature review including suggestions for prevention. Br J Sports Med. 2013;47(18):1139–1143. doi: 10.1136/bjsports-2013-092886
31. Powell JR, Boltz AJ, Robison HJ, et al. Epidemiology of injuries in national collegiate athletic association of men's wrestling: 2014-2015 through 2018-2019. J Athl Train. 2021;56(7):727–733. doi: 10.4085/1062-6050-429-20
32. Myers RJ, Linakis SW, Mello MJ, et al. Competitive wrestling-related injuries in school aged athletes in U.S. emergency departments. West J Emerg Med. 2010;11(5):442–449.
33. Schuller DE, Dankle SK, Martin M, et al. Auricular injury, and the use of headgear in wrestlers. Arch Otolaryngol Head Neck Surg. 1989;115(6):714–717. doi: 10.1001/archotol.1989.01860300068019
34. AIBA. AIBA Open boxing (AOC) competition rules. Lausanne: AIBA; 2013.
35. McIntosh AS, Patton DA. Boxing headguard performance in punch machine tests. Br J Sports Med. 2015;49(17):1108–1112. doi: 10.1136/bjsports-2015-095094
36. McIntosh AS, Andersen TE, Bahr R, et al. Sports helmets now and in the future. Br J Sports Med. 2011 Dec;45(16):1258–1265. doi: 10.1136/bjsports-2011-090509

37. McIntosh AS, Patton DA. The impact performance of headguards for combat sports. Br J Sports Med. 2015;49(17):1113–1117. doi: 10.1136/bjsports-2015-095093
38. O'Sullivan DM, Fife GP. Impact attenuation of protective boxing and taekwondo headgear. Eur J Sport Sci. 2016;16(8):1219–1225. doi: 10.1080/17461391.2016.1161073
39. Finan JD, Nightingale RW, Myers BS. The influence of reduced friction on head injury metrics in helmeted head impacts. Traffic Inj Prev. 2008 Oct;9(5):483–488. doi: 10.1080/15389580802272427
40. Gilchrist A, Mills NJ. Protection of the side of the head. Accid Anal Prev. 1996;28(4):525–535. doi: 10.1016/0001-4575(96)00030-9
41. Hrysomallis C. Impact energy attenuation of protective football headgear against a yielding surface. J Sci Med Sport. 2004;7(2):156–164. doi: 10.1016/S1440-2440(04)80005-7
42. McIntosh AS, McCrory P. Impact energy attenuation performance of football headgear. Br J Sports Med. 2000;34(5):337–341. doi: 10.1136/bjsm.34.5.337
43. Pieter W, Fife GP, O'Sullivan DM. Diminished impact attenuation properties of taekwondo and boxing headgear [abstract], 5th IOC world conference on prevention of injury & illness in sport 2012. Br J Sports Med. 2014;48(7):652. doi: 10.1136/bjsports-2014-093494.246
44. Tierney RT, Higgins M, Caswell SV, et al. Sex differences in head acceleration during heading while wearing soccer headgear. J Athl Train. 2008;43(6):578–584. doi: 10.4085/1062-6050-43.6.578
45. Withnall C, Shewchenko N, Wonnacott M, et al. Effectiveness of headgear in football. Br J Sports Med. 2005;39(Suppl 1):i40–8. doi: 10.1136/bjsm.2005.019174
46. Bartsch AJ, Benzel EC, Miele VJ, et al. Boxing and mixed martial arts: preliminary traumatic neuromechanical injury risk analyses from laboratory impact dosage data. J Neurosurg. 2012;116(5):1070–1080. doi: 10.3171/2011.12.JNS111478
47. Stojsih S, Boitano M, Wilhelm M, et al. A prospective study of punch biomechanics and cognitive function for amateur boxers. Br J Sports Med. 2010;44(10):725–730. doi: 10.1136/bjsm.2008.052845
48. Pierce JD, Reinbold KA, Lyngard BC, et al. Direct measurement of punch force during six professional boxing matches. J Quant Anal Sports. 2006;2(2):1–19. doi: 10.2202/1559-0410.1004
49. Smith MS. Physiological profile of senior and junior England international amateur boxers. J Sports Sci Med. 2006;5(CSSI):74–89.
50. Zhang L, Yang KH, King AI. A proposed injury threshold for mild traumatic brain injury. J Biomech Eng. 2004;126(2):226–236. doi: 10.1115/1.1691446
51. Haug RH, Savage JD, Likavec MJ, et al. A review of 100 closed head injuries associated with facial fractures. J Oral Maxillofac Surg. 1992;50(3):218–222. doi: 10.1016/0278-2391(92)90315-Q
52. Ommaya AK, Goldsmith W, Thibault L. Biomechanics, and neuropathology of adult and paediatric head injury. Br J Neurosurg. 2002;16(3):220–242. doi: 10.1080/02688690220148824
53. Post A, Hoshizaki BT. Rotational acceleration, brain tissue strain, and the relationship to concussion. J Biomech Eng. 2015;137(3). doi: 10.1115/1.4028983
54. Walilko TJ, Viano DC, Bir CA. Biomechanics of the head for Olympic boxer punches to the face. Br J Sports Med. 2005;39(10):710–719. doi: 10.1136/bjsm.2004.014126
55. Delaney J, Puni V, Rouah F. Mechanisms of injury for concussions in university football, ice hockey, and soccer: a pilot study. Clin J Sport Med. 2006;16(2):162–165. doi: 10.1097/00042752-200603000-00013
56. Li H, Lu RJ, Wu P, et al. Numerical simulation, and analysis of midfacial impacts and traumatic brain injuries. Ann Transl Med. 2021;9(6):459. doi: 10.21037/atm-21-134
57. Atha J, Yeadon MR, Sandover J, et al. The damaging punch. Br Med J (Clin Res Ed). 1985;291(6511):1756–1757. doi: 10.1136/bmj.291.6511.1756
58. Joch W, Fritche P, Krause I. Biomechanical analysis of punching boxing: In: Morecki A, Fidelus K Kedzior K, Biomechanics VII-A. Baltimore (MD): University Park Press, p. 343–349:1981.
59. Roberts AH. Brain damage in boxers: a study of the prevalence of traumatic encephalopathy among ex-professional boxers. London: Pitman Medical and Scientific Publishing; 1969.
60. Smith PK, Hamill J. The effect of punching glove type and skill level of momentum transfer. J Hum Mov Stud. 1986;12(3):153–161.
61. Cournoyer J, Hoshizaki TB. Head dynamic response and brain tissue deformation for boxing punches with and without loss of consciousness. Clin Biomech (Bristol, Avon). 2019;67:96–101.
62. Fife GP, O'Sullivan DM, Pieter W, et al. Effects of Olympic-style taekwondo kicks on an instrumented head-form and resultant injury measures. Br J Sports Med. 2013;47(18):1161–1165. doi: 10.1136/bjsports-2012-090979
63. Davis P, Waldock R, Connorton A, et al. Comparison of amateur boxing before and after the 2013 rules change and the impact on boxers' safety. Br J Sports Med. 2018;52(11):741–746. doi: 10.1136/bjsports-2017-097667
64. Davis P, Connorton AJ, Driver S, et al. The activity profile of elite male amateur boxing after the 2013 rule changes. J Strength Cond Res. 2018;32(12):3441–3446. doi: 10.1519/JSC.0000000000001864
65. Lystad RP, Alevras A, Rudy I, et al. Injury incidence, severity and profile in Olympic combat sports: a comparative analysis of 7712 athlete exposures from three consecutive Olympic games. Br J Sports Med. 2021;55(19):1077–1083. doi: 10.1136/bjsports-2020-102958
66. Bianco M, Loosemore M, Daniele G, et al. Amateur boxing in the last 59 years. Impact of rules changes on the type of verdicts recorded and implications on boxers' health. Br J Sports Med. 2013;47(7):452–457. doi: 10.1136/bjsports-2012-091771
67. Dickinson P, Rempel P. Prohibiting headgear for safety in amateur boxing? Opinion of the Canadian boxing community: an online poll. Sports Med - Open. 2016;2(1):1–11. doi: 10.1186/s40798-016-0043-2
68. Sethi N. In response to use of headguards in AIBA boxing tournaments—a cross-sectional observational study. Clin J Sport Med. 2018;28(1):e1. doi: 10.1097/JSM.0000000000000401
69. Casson IR, Viano DC, Powell JW, et al. Twelve years of national football league concussion data. Sports Health. 2010;2(6):471–483. doi: 10.1177/1941738110383963
70. McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effect and recovery time following concussion in collegiate football players: the NCAA concussion study. JAMA. 2003;290(19):2556–2563. doi: 10.1001/jama.290.19.2556
71. Center for Disease Control and Prevention. Answering questions about chronic traumatic encephalopathy (CTE).https://www.cdc.gov/traumaticbraininjury/pdf/CDC-CTE-FactSheet-508.pdf. Accessed 15May2023.
72. National Institute of Neurological Disorders and Stroke. Focus on traumatic brain injury research. https://www.ninds.nih.gov/current-research/focus-disorders/focus-traumatic-brain-injury-research. Accessed 15May2023.
73. Emery CA, Black AM, Kolstad A, et al. What strategies can be used to effectively reduce the risk of concussion in sport? A systematic review. Br J Sports Med. 2017;51(12):978–984. doi: 10.1136/bjsports-2016-097452
74. Knight J, Nguyen JVK, Mitra B, et al. Soft-shell headgear, concussion, and injury prevention in youth team collision sports: a systematic review. BMJ Open. 2021;11(6):e044320. doi: 10.1136/bmjopen-2020-044320
75. Schneider DK, Grandhi RK, Bansal P, et al. Current state of concussion prevention strategies: a systematic review and meta-analysis of prospective, controlled studies. Br J Sports Med. 2017;51(20):1473–1482. doi: 10.1136/bjsports-2015-095645
76. Willick SE, Wagner G, Ericson D, et al. Helmet use and risk-taking behavior among Skiers and Snowboarders. Clin J Sport Med. 2019;29(4):329–335. doi: 10.1097/JSM.0000000000000527
77. Phillips RO, Fyhri A, Sagberg F. Risk compensation and bicycle helmets. Risk Anal. 2011;31(8):1187–1195. doi: 10.1111/j.1539-6924.2011.01589.x