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Concussions, cuts and cracked bones: A systematic literature review on protective headgear and head injury prevention in Olympic boxing

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ABSTRACT

In 2013, the International Boxing Association (AIBA) prohibited the use of headguards for elite male Olympic boxing competitions. Could the removal of the headguard from elite male boxing competitions potentially cause increased injury risk for boxers? The aim of the literature review is to analyse current knowledge about the use of protective headgear and injury prevention in boxing, in order to determine if there are increased injury risks associated with headguard use. Peer-reviewed studies (language: English, Norwegian, Swedish, Danish and Dutch) published from 1980 and onwards were considered. Five academic databases and grey literature sources were searched, and articles were assessed for methodological quality. Only studies that included boxers as the study population with headguards as a factor were considered. A total of 39 articles were included in the review. The analysis of the reviewed literature indicates that headguards protect well against lacerations and skull fractures, while less is known about the protective effects against concussion and other traumatic brain injuries. Most of the analysed studies however use indirect evidence, obtained through self-report or observational techniques with relatively small non-representative samples. There are almost no randomised control trials, longitudinal research designs or samples from recreational boxing. Therefore, AIBA's decision to remove the headguard has to be seen with caution and injury rates among (male) boxers should be continuously evaluated.

KEYWORDS

Injury and prevention; physiology; medicine; sociology; policy

Highlights

- Research does not sufficiently support the statement that boxing without protective headgear is safer than boxing with a headguard.
- Headguards protect well against facial cuts and skull fractures. The systematic review indicates that headguards provide some protection against linear impacts to the head. The headguards protective effects against concussion are however uncertain.
- A research agenda is proposed. Priority areas include a focus on longitudinal research designs, randomized control trials, samples from recreational competitive boxing, as well as further research into coaches' and athletes' experiences and perspectives on headguards and injuries.


1. Introduction

By its very nature, boxing carries risk of sustaining injuries. Olympic boxing (also known as AIBA boxing or

amateur boxing) refers to the type of boxing competitions that are included in the Olympic Games. Olympic boxing competitions consist of 3 × 3 min rounds, with 1 min break between each round. Compared to professional boxing, Olympic boxing competitions are substantially shorter in duration and the gloves are significantly heavier padded. Subsequently, Olympic boxing is often perceived as safer than professional boxing. Even with the safety measures in Olympic boxing today (e.g. limited number of rounds per bout, heavier padded gloves, mouthguards and quarantine after sustaining knockout), boxers still run the risk of sustaining head injuries, ranging from cuts to intracranial trauma and changes in the brain cellular biomarkers post-fight (Alevras, Lystad, Soligard, & Engebretsen, 2018; Davis, Waldock, Connorton, Driver, & Anderson, 2017; Graham et al., 2011).

Headguards for boxers were first introduced in 1984 at the Los Angeles Olympic Games. Similarly to the addition of heavier padded gloves and the

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standardisation of the number of rounds in earlier boxing history, headguards were introduced as a safety measure to protect the athletes' health (McCrory, Falvey, & Turner, 2012; Loosemore, Knowles, & Whyte, 2007; Tjønnndal, 2016). In 2013, the International Boxing Association (AIBA) implemented new technical rules for Olympic boxing competitions prohibiting the use of protective headgear for male elite boxers. The removal of the men's headguards was based on arguments that using headguards provided boxers with a false sense of security, causing them to take more risks in the ring and sustain more head injuries (AIBA, 2015). However, women, youth and junior boxers are still required to wear headguards, with little rationale provided for this distinction in rulings from the men's competition (McCrory et al., 2012).

There are arguments both pro and contra the use of protective headgear in Olympic boxing. Some of the common arguments for keeping the headguard on are: (1) that it provides better protection of the boxer's head because of the shock absorbing layer between the head and the gloves, and (2) that it protects well against head injuries such as cuts and hematomas (Bartsch, Benzel, Miele, Morr, & Prakash, 2012a; 2012b; Razaghi, Biglar, & Karimi, 2018). On the contra side, there are arguments that using protective headgear in sports increases risk taking behaviour (Bambach, Mitchell, Grzebieta, & Olivier, 2013; Willick et al., 2019). Therefore using a headguard could provide a false sense of security that causes the boxers to "lead with the head" and take more risks in the ring (AIBA, 2015). Another argument against the headguard is that it does not eliminate the risk of contracting a concussion during a fight (Loosemore, Lightfoot, & Beardsley, 2015a).

The topic of sport, protective headgear and head injuries has gained increased public and scholarly attention the last years, including studies in sports such as rugby (Gardner et al., 2015), American football (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004), ice hockey (Smith et al., 2017), soccer (Vedung, Hänni, Tegner, Johansson, & Marklund, 2020) and cycling for transport and recreation (Høye, 2018). All studies on the topic of head injuries in sport concern important aspects of athlete safety and health in both elite, amateur and youth sport. Still, with the recent rule change in mandatory equipment in boxing competitions, it is highly relevant to explore what research says about head injuries and protective headguards in Olympic boxing now.

Therefore, the purpose of this review is: (i) to summarise the existing literature on headguards and injury prevention in boxing; (ii) to establish what the headguard does and does not protect against in terms of athlete

injuries and additionally, (iii) to ascertain if there are increased injury risks associated with headguard use. With this literature review we aim to propose a renewed research agenda in the field of protective equipment and athlete's safety in boxing.

2. Materials and methods

This literature review of existing research on boxing, protective headgear and injuries has been conducted and reported according to the 27-item PRISMA protocol for systematic reviews (Liberati et al., 2009). See Appendix 1 (supplementary material) for a detailed description of the reporting process.

2.1 . Search strategy and selection criteria

Five academic databases were searched between February 2019 and May 2020. The databases searched were SPORTDiscus, ERIC, PubMed, PsycINFO and ISI Web of Science. These databases were selected because they collectively provide insight into biomedical, behavioural and social science research on head injuries in Olympic boxing. A Boolean search was undertaken in each database using the following search string: "boxing" AND "concussion OR brain injury OR head injury" AND "headgear OR headguard". Additionally, searches of grey literature were performed to identify other studies published in English that may not have been identified through the database searches. Grey literature search included an examination of reference list material in the identified studies.

A series of specific inclusion and exclusion criteria were set to check the eligibility of titles, abstracts, and full-text articles. The inclusion criteria stipulated that studies included in the review should:

- (1) be reported in peer-reviewed journals and published in English
- (2) be an original study, a theoretical paper or a review article
- (3) include a sample and population of interest consisting of boxers (junior/youth/elite level, recreational or competitive) or include boxing/boxers as one of the sample groups
- (4) focus on protective headgear and head injury in boxing (not in other contact sports such as e.g. soccer).

The rationale for these criteria concerned a need to identify international academic publications on headguards and head injuries in Olympic boxing.

2.2 . Procedure and analysis

Studies for review were identified through four steps. Firstly, the Boolean search of title, abstracts and keywords was undertaken to identify articles that fitted within the inclusion criteria. Secondly, full text articles were divided between the authors and assessed independently for eligibility by one of the four authors. At this stage, several articles were removed from the review for the following reasons: the study did not include boxers/boxing as a sample, duplication with a previously identified article, or the article did not describe headguards in relation to head injuries. Thirdly, questions regarding the inclusion and exclusion of articles were discussed and resolved collectively through joint analysis by the remaining three authors. Finally, the quality of the studies was assessed to ensure reliability.

2.3 . Article quality and risk of bias assessment

For the medical studies ($n = 16$) included in the review, the level of evidence (LOE) and quality assessments were performed. The LOE estimation was based on the study of Ackley, Swan, Ladwig, and Tucker (2008), and includes an evaluation of the methodological quality of the design, validity, and applicability to the subjects included in this review (see Appendix 2, supplementary material). Quality assessment was based on published checklists produced to evaluate epidemiological studies that assess potential links between exposures to risk factors in boxing and medical outcomes. Because the review included several types of study designs, we used two different quality assessment tools. For the observational cohort and cross-sectional studies we used the tool developed by the NIH (see Appendix 3, supplementary material). For the quality assessment of the included review papers, the checklist of the PRISMA Group was used (see Appendix 4, supplementary material). The above-mentioned quality assessment tools to determine the level of evidence could not be meaningfully applied to the included studies that do not use experimental designs (i.e. RCT/ Cohort) and fall within the field of social sciences (Hammersley, 2013). For those studies, the quality of the research design was assessed and the decision to either in- or exclude the studies was made by the four authors of this review paper.

The risk of bias of all included articles was assessed by the four authors independent of each other during the review of the full text articles. If there was uncertainty related to questions of bias in an individual study, a consensus was reached among the authors (Page, McKenzie,

& Higgins, 2018). The bias assessment included four factors: study population and sample, measurement selection and controlling of confounding variables, analysis approaches, funding and disclosure of interest. Among the reviewed literature, eight papers were considered to have a degree of bias (Benson, Hamilton, Meeuwisse, McCrory, & Dvorak, 2009; Davis et al., 2017; Howell et al., 2017; Loosemore et al., 2007; Loosemore et al., 2015a; Siewe et al., 2015; Zazryn, McCrory, & Cameron, 2009; Zazryn et al. 2006). The articles with identified bias included bias of sample (Benson et al., 2009; Davis et al., 2017; Howell et al., 2017; Siewe et al., 2015; Zazryn et al., 2009; Zazryn, Cameron, & McCrory, 2006), measurement selection (Davis et al., 2017; Siewe et al., 2014; Zazryn et al., 2006) and analysis approaches (Loosemore et al., 2007; Loosemore et al., 2015a; Zazryn et al., 2009). Specific descriptions of our assessment of bias in these studies can be found in Table 2. In our analysis of literature, we have considered these studies as relevant contributions to the field, but with weaknesses in terms of sample and measurement selection and analytical approach. These issues weaken the validity of the research.

3. Results

3.1. Systematic review findings

534 peer-reviewed studies (Figure 1) reported in academic journals were located through our Boolean search string applied to the databases SPORTDiscus, ERIC, PubMed, PsycINFO and ISI Web of Science (Table 1). Twenty one papers were identified through other sources. After removing duplicates and applying the inclusion criteria to the titles and abstracts, 45 potentially relevant studies were included for the full text examination. From those potentially relevant studies 6 papers were excluded because they did not involve headguards and concussion in boxing. This resulted in a final sample of 39 articles included in our literature review. The reviewed literature is summarised in Table 2. Complete references of the included studies can be found in the reference list of this article.

3.2. Head injuries in boxing: when, where and what?

Head injuries are a complex area of study. The changes in neurologic function associated with concussion often present rapidly and resolve spontaneously (Malcolm, 2019). Consequently, many concussions go unreported and unrecognised by both athletes and coaches (Malcolm, 2019; Ventresca & McDonald, 2019).

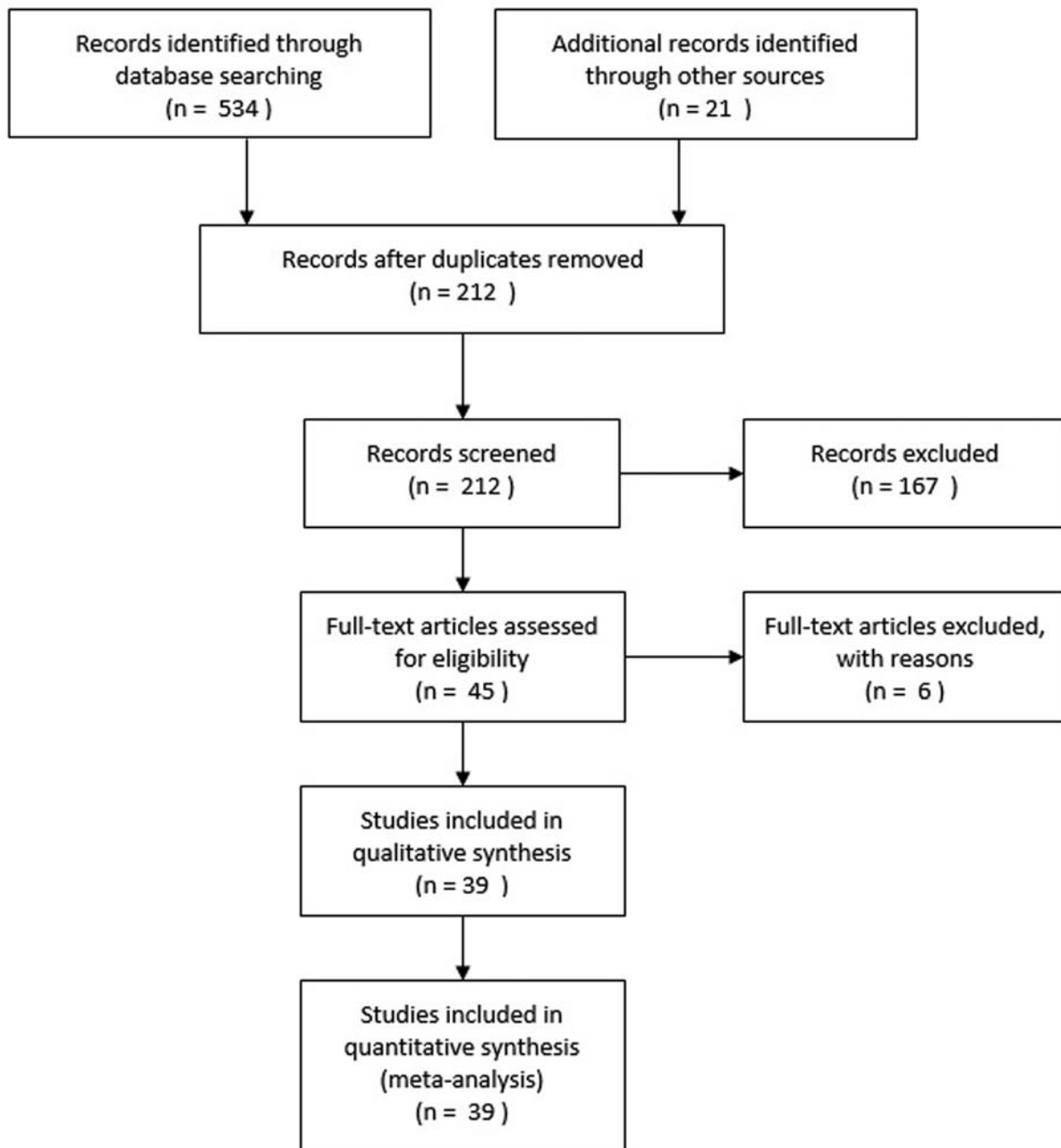


Figure 1. PRISMA flow chart of the review process.

This is illustrated by the proportion of head injuries reported in the reviewed literature, which varies from 10% to 70% of all injuries depending on the study

Table 1. Overview of initial database search results.

Source	Database type	Results returned	Selected studies
SPORTDiscus	Sports Science	9	7
ERIC	Education research	1	0
PubMed	Medical research	487	21
PsycINFO	Behavioural science	28	2
ISI Web Of Science	General academic database	9	9

design (Lubell, 1989; Welch, 1986; Jordan & Voy, 1990; Timm et al., 1993; Zazryn et al., 2006; Zazryn, Finch, & McCrory, 2003), and has led to some researchers to argue that athlete and coach education is the most effective preventative measure against head injuries (Daneshvar et al., 2011). In their longitudinal injury surveillance study (over 5 years) of medically diagnosed injuries in the British national boxing team from 2005 to 2009, Loosemore et al. (2015b) found that hand injuries are the most prevalent boxing injuries. Furthermore, Loosemore et al. (2015b) concluded that more injuries occur during training than during competition and

Table 2. Results of literature review.

Authors	Aim	Sample	Method & Measures	Findings
Bartsch et al. (2012a)	Compare the protective effect of various glove & head padding	Anthropomorphic test device (ATD)	ATD struck by 54 pendulum impacts replicating hook punches at low and high energy	Boxing glove & headgear provides the best overall head and neck injury protection for competitors
Bartsch et al. (2012b)	Test ATD neck-response rate to direct head impacts	5 padding conditions tested ATD with linear accelerometer, triaxial rate sensor. 54 impact trails performed	Measured force in three directions at 5000 Hz by a 3.6 kg steel sphere impact pendulum	Impacts producing highest ATD resultant centre of gravity linear acceleration resulted in the lowest resultant occipito-cervical spine bending force
Beckwith et al. (2007)	Validate an instrumented boxing headgear that can be used to measure impact severity and location	ATD with Everlast 6202 medium boxing headgear	56 impacts over 3 speeds and 5 locations to simulate blows most commonly observed in boxing. Headgear instrumented with 12 single-axis linear accelerometers	Using instrumented boxing headgear will allow ringside physicians to be aware of potentially injurious impacts and cumulative impact history not resulting in knockout
Benson et al. (2009)	Systematic review paper on the effects of all types of equipment use on concussion prevention	51 studies from 12 electronic databases	Systematic review paper. Quality of evidence was assessed, strength of study design, sample size/ power calculation and selection bias	Selection bias and lack of measurement and control for potentially confounding variables was a concern in the reviewed literature. Comparison between studies are difficult due to the variability in research designs
Bianco et al. (2013)	Assess impact of changing rules on rate of KO and RSC	Olympic boxing 1952-2011: 29357 boxing matches	Rate of KO/RSC/RSC-H/RSC-I/RSC-O/abandon/disqual./points decisions after different rule changes	Rule changes induced reduction in health challenging further rule changes
Bianco et al. (2005)	To collect medical information from mandatory pre-competition and post-competition examinations for all fights involving Italian female boxers in 2002-2003.	1) 664 professional and amateur female boxers - 321 bouts 2) 28 amateur female boxers	Retro- and prospective study	97.1% of the boxers had no lesions. Following injuries were recorded: epistaxis facial haematomae, maechymosis, bruising of eyebrow region, hand-wrist contusion, distractive lesion to femoral biceps. 3 out of 40 fights were stopped before the time limit.
Candy et al. (2017)	Test protective capabilities of headgear in novel viscoelastic material	75 male Sprague Dawley rats	5 groups (control), 37G vs 106G impact with/without headgear: serum TNF- α , NEF-L, GFAP coordination, exploratory/locomotor behavior.	Novel headgear significantly protects against mTBI symptoms and biomarkers in average impact, moderately in heavy impact group
Cournoyer & Hoshizaki (2019)	Compare magnitudes of head acceleration and brain tissue deformation for punches resulting in a loss of consciousness and punches that do not.	400 professional boxing fights and reconstruction of impacts	Video analysis and reconstruction of impacts using anthropometric headform and finite element model	Loss of consciousness in boxing resulted from hooks to the side of the mandible creating high levels of rotational acceleration and increased magnitudes of brain trauma
Daneshvar et al. (2011)	Discuss the injury preventative effect of helmets and mouth guards in sport	None	Conceptual/meta review	Rule changes/enforcement and player/coach education is the most preventative measure against concussion. Headgear protect against skull fractures, TBI and death. Mouthguards do not protect against concussion
Davis et al. (2017)	Effect of rules changes in 2013 on amateur boxing strategy, technique and safety (compared to pre-2013)	99 male boxers	Analysis of video footage of 29 Olympic (pre-2013) and 50 world championship bouts (post-2013) through a "simplistic hand-tally method"	Increased risk of concussive brain injury post-2013 as well as increase in skin splits, technical knock outs and punches to the head. Post-2013 boxers increased defensive movements and footwork. Percentage of standing counts changed from 9% (pre-2013) to 3% (post-2013). Pre-2013 1.7% did not last the full duration because of the referee stopping the contest. Post-2013 4.2% did not last the full duration as a result of (technical) knock out
Dickinson and Rempel (2016)	Investigate the stance of the boxing community to headgear use in competition	636 responses (boxers, parents of boxers, coaches, officials)	Online open access poll (anonymous)	Large majority supports mandatory headgear use in amateur boxing (71,5%). Females were more in favour of mandatory headgear and more against banning. Active boxers were more amenable to conditional removal of headgear, but strongly against its prohibition

(Continued)

Table 2. Continued.

Authors	Aim	Sample	Method & Measures	Findings
Erlanger (2014)	Provide an updated characterisation of CTBI in boxing and other sports	None	Examines the utility of exposure models for understanding CTBI in boxers	Research on sport-specific phenotypes of CTBI should be performed clinically, using broad neurological, neuropsychological and behavioural measures to ensure a comprehensive consideration of symptoms
Estwanik, Boitano, and Ari (1984)	Analyse the injury stats of a tournament	547 bouts with 1.094 participants	Analysis of injuries statistics for the 1981 and 1982 USA/Amateur Boxing Federation National Championship	Most frequent injuries were head blows, soft-tissue hand injuries, facial lacerations. 48 matches stopped because of head blows
Falvey and McCrory (2015)	Illustrate a specific medical risk with the rule change of removing the headguard	A 22-year-old male boxer with 5 years senior international experience that suffered a subdural hematoma	Clinical examination and a SCAT3 assessment following a concussion. Video analysis of bouts against the same opponent, both with and without headgear	Without the headgear the total punches increased, as well as head clashes and blocked punches to the head. The total impacts to the head increased by 36%.
Follmer, Varga & Zehr (2020)	Investigate concussion knowledge among athletes and coaches	70 athletes and 35 coaches	Online survey	Merely 5.7% of coaches properly recognised the level of traumatic brain injury a concussion represents, 68.8% were unfamiliar with any sideline assessment tools, and only 14.3% often seek out concussion knowledge
Haglund and Eriksson (1993)	Find out if amateur boxers whose career started mainly after the introduction of changes in rules and regulations had suffered any chronic brain damage.	410 boxers	Retrospective study, using Randomised Control Trial from 410 boxers with control groups. Sample of 50 boxers randomly selected	No significant differences between the groups in any of the physical or neurological examinations. A significant higher incidence of slight or moderate electroencephalography deviations among the boxers. Indications of slight brain dysfunction in some of the amateur boxers
Howell et al. (2017)	Examine the neurocognitive, postural, dual-task and visual abilities of female Olympic boxers before and after participation in a tournament	61 female boxers	Prospective evaluation using standardised tests with female elite boxers before and after tournament to measure neuro-cognitive functions (e.g. balance, vision, precision)	No concussions were diagnosed during the tournament, and no boxers were stopped early due to suspected concussion.
Jordan et al. (1990)	Determine types of acute and chronic injuries sustained by elite amateur boxers during training, sparing and competition	447 injuries were registered at the US Olympic Training Centre	Data collection between January 1977-August 1987. Registration done by the sports medicine staff	Participation in a boxing tournament did not lead to worse performance on neurological tests that assessed balance control or mobility
Loosemore et al. (2007)	Evaluate risk of cTBI from amateur boxing	36 scientific papers	Systematic review of observational studies on cTBI 1950-2007.	Reported injuries: upper extremity: 32.9%, lower extremity: 23.9%, head & face: 20.5%, back: 6.9%, cerebral injuries: 6.5% (28 out of 29 were concussions & 1 traumatic headache), cervical spine: 5.1%
Loosemore et al. (2015a)	Assess the proportion of injuries that occur in each anatomical location during boxing competition or training, as reported in observational studies in professional and amateur boxers	5020 described injuries from 15 articles (4 prospective studies; 11 cross-sectional (retrospective) studies)	Systematic review of proportion of injuries in each major anatomical region	No strong evidence cTBI-amateur boxing. The better the study quality, the lower the association cTBI-boxing
Loosemore et al. (2015b)	Reviewed injuries in the Great Britain amateur boxing squad between 2005–2009	66 boxers	Longitudinal, prospective injury surveillance over 5 years	Most common injury region in professional and amateur boxing is the head. 1/3 of studies reported no concussions or neural/cerebral injury of any kind
Lubell (1989)	Compare brain damage in amateur vs prof boxing	None	Conceptual/meta review	More injuries affected the hand. More injuries occurred during training than during competition. The incidence of concussion is comparatively low
McIntosh and Patton (2015a)	Present a novel method for assessing boxing headguard impact performance	Anthropomorphic test device (ATD) fitted with and without headguard (top ten and Adidas)	Development of a linear impactor built for delivering repeatable impacts to recreating boxing blows. Repeated tests at different speeds	Brain damage is linked to number of punches on the head Complete ban vs better follow-up: registration of number of fights, no blow on the head, medical follow up pre/post competition Peak impact force (both linear and angular head acceleration) were substantially reduced by headguards compared to the bare head. AIBA approved headgear in combination with gloves offer a large level of protection to the boxers' head

McIntosh and Patton (2015b)	Assess the impact energy performance of a range of headguards in combat sports	7 headguards worn during combat sport training/competition, including 2 AIBA approved models	Drop tests conducted against a flat rigid anvil both with and without a boxing glove section. Total of 213 impact tests conducted	Best performing headguards were the thickest and the heaviest. Top ten performed better than Adidas boxing models demonstrated that performance deteriorated with repeated impacts
McCroory et al. (2012)	Discuss the increased move towards a more aggressive professional-style of amateur boxing in AIBA since 2007	None	Conceptual/meta review	More independent research on the protective effects of headguards, gloves and mouth guards need to be promoted rather than changing the rules of amateur boxing without sufficient evidence
Moore (1980)	Discuss what medicine can do to make boxing safer	None	Conceptual/meta review	Headgear not useful because does not prevent acceleration/deceleration forces. Rules from amateur box should be copied to professional boxing. Physician should have the right to stop the fight
Morarity et al. (2012)	Evaluate pre and postbout cognitive performance in motivated amateur boxers concussive injury	96 competing boxers	Computerised cognitive assessment tool (CCAT, Axon Sports)	Cognitive impairment, as detected by subtle deterioration in reaction time measures, can occur in amateur boxer's post-bout that is not recognised at ringside
Nash (1985)	Discuss strategies to make boxing safer	1 medical doctor	Qualitative interview	Better training following modern training methods computerised registers of boxers and injuries; physician should be allowed to stop a contest
Oilman, Rose, and Aflou (1983)	Investigate different types of boxing injuries	Registered boxing injuries in the British Army from 1969–1980	Review of Army Hospital and medical records	On average 35 boxing injuries a year. No deaths, but 10 medical discharges due to injuries sustained from boxing. Head injuries most prevalent, especially in young and inexperienced boxers. Concussion is the most common injury
O'Sullivan and Fife (2016)	Compare impact attenuation performance of boxing and taekwondo headgear in terms of peak linear and rotational acceleration	In vitro (i.e. lab) impact test of 4 types of headgear (2 for boxing – Adidas and Greenhill)	A lab-based testing procedure on 2 boxing headgears	The headgears tested failed the ASTM high impact test requirements to reduce the linear acceleration to below a threshold of 150 g. With a high frequency of impacts to the front of the head in boxing, it is useful to improve impact attenuation at the front of headgear by improving the material properties Thickness of headgear padding did not always correspond with a reduction in head acceleration
Razaghi et al. (2018)	Compare performance of 3 different materials, i.e. the expanded propylene (EPP), expanded polystyrene foam (EPS), and polyvinyl alcohol sponge (PVA), in reducing the amount of injury as a result of a right hook to the face.	No human subjects were used.	Tests were performed on a biomechanical "test bench" with a 3D Finite Element model of the human skull. Each of the EPP, EPS, and PVA materials was simulated separately to compute their effectiveness in controlling the amount of injury. A combination of all of these 3 materials were made and subjected to the same loading procedure	The EPS will keep its mechanical properties independent to the amount of the loading rates; EPS can minimise the amount of von Mises stress in the face while the PVA sponge could well absorb the energy of the punch; Composite structure of the 3 materials can significantly diminish the injury in the skull
Schmidt-Olsen, Jensen, and Mortensen (1990)	Study preventive measures for brain injury in Danish amateur boxing	5272 Danish amateur boxing matches (3240 were elite matches)	Survey of amateur boxing matches + prophylactic intervention: unlimited length of hand bandage, voluntary use of headguards, and heavier gloves	None of the interventions affected the frequency of matches being stopped because of knock outs or blows to the head
Siewe et al. (2015)	Analyse the rates and types of injuries in competitive boxing (amateur & professional)	44 competitive boxers	Self-report monthly questionnaire (oct 2012 – sept 2013)	Injury rate is not a function of age. Injuries to the head (eyebrow, nose) and upper limbs most common. Head injuries with neurological symptoms rarely occur. 12.8 injuries per 1000 h of training, injury frequency sign. correlated with the number of bouts/year. 65% of injuries occur during training
Stojish et al. (2010)	Evaluate biomechanical factors of the head during a sparring session and their link to cognitive function	27 male and 28 female amateur boxers	Instrumented Boxing Headgear was used during a 2 min sparring session; IMPACT Concussion management software;	Significant higher peak translational acc. HIC and GSI in male compared to female; Significant decrease in delayed memory post-bout scores for both genders.

(Continued)

Table 2. Continued.

Authors	Aim	Sample	Method & Measures	Findings
Timm et al. (1993)	Describe injuries in amateur boxing from 1977–1992	Injuries that have occurred at the United States Olympic Training Center	Neurocognitive tests; Main outcome measures: head accelerations; Head Injury Criteria (HIC); Gadd Severity Index (GSI) Data derived from the Olympic centre's medical report system, including information about the cause and nature of the injury	No sign difference between genders for the cognitive function data (memory, attention, reaction time, problem solving) A total of 1776 injuries reported in boxing during this period. Arm/hand injuries most prevalent (24.8%), followed by head injuries (19.4%). 6.1% concussions reported, 4.9% fractures and 4.1% cuts. Risk of concussion is not higher in amateur boxing than in other sports
Zazryn et al. (2009)	Determine injury rates and risk factors for injury in a cohort of professional boxers	545 professional boxers who participated in a total of 907 fights in Victoria (Australia) from 1997–2005	Retrospective cohort design (1997–2005) based on physician reports	Majority of injury were open wounds lacerations to the head/face, concussions, and fractures to hands. Increasing age and numbers of fights significant predictors of injury. TKO and KO almost triples the injury rate (23.6 per 110 fights, to 60.7). Potential for increased injury risk between 18–23yrs and between 28–35 years Less than 4% injuries in the program
Welch (1986)	Describe injury pattern and safeguards in an US Army boxing program	2100 US Army Cadets from 1983–1985	Statistics of Injury rates	
Zazryn et al. (2006)	Determine the epidemiology of injury and exposure of amateur and professional boxers. Describe the incidence of acute injury and potential exposure to injury for amateur and professional boxers.	34 amateur and 13 professional boxers. A total of 4120 training sessions were documented, with 2366 including sparring	Prospective study, self-report survey, observations (3times for each boxer), structured observations during all boxing matches (and verification with official registration)	Of the 21 injuries sustained by the cohort during competition, 70% were to the head, with almost half of the injuries to this region being concussions (47%). Boxers sustain considerably more injuries per hour of competition than per hour of training, however the low level of competition exposure makes participation in the sport acceptable in terms of injury risk 107 registered injuries. 89.8% of registered injuries concerned the head/neck/face, 7.4% to upper extremities. Eye injuries (45.8%) and concussion (15.9%) most common
Zazryn et al. (2003)	To identify injury risk in boxing and suitable means for preventing injuries	A total of 427 fights were reviewed in professional boxing in Victoria (Australia) from 1985–2001	Review of fight outcomes and injury data	

that the incidence of concussion among their sample was low compared to similar studies of other full contact sports.

A critical issue when interpreting the current scientific evidence regarding the use of headguards for preventing head injuries is that headguard rules were installed along with other rule changes that could also have influenced head injury risks (Bianco et al., 2013). Hence, it is difficult to say which preventative effects are due to using headguards and which are due to other changes, such as, for example, rule modifications or improved education programs for coaches, fight doctors and boxing officials.

Collectively, the reviewed literature provides some insights into prevalent injuries in competitive boxing. Firstly, while Loosemore et al. (2015b) found most injuries to occur during training, Zazryn et al. (2006) determined that most injuries occur during competition and that injuries sustained in training are less severe compared to injuries sustained during competition. Additionally, Zazryn et al. (2009) show that the risk of sustaining head injury increases as the athlete ages. Secondly, the most frequent injuries are head injuries (i.e. concussion, cuts, skull fractures) and injuries to the hands and arms (Bianco et al., 2005; Jordan & Voy, 1990; Zazryn et al., 2009). The complexity of studying concussion and traumatic brain injury (TBI) is exemplified in the reviewed literature through the substantial variation in reported concussion rates, from 6.1% (Timm et al., 1993) to 75% (Loosemore et al., 2015a; Zazryn et al., 2006). The difference in concussion rates between studies also supports research indicating that concussions are notoriously under-reported in competitive sports (Kroshus, Garnett, Hawrilenko, Baugh, & Calzo, 2015; Malcolm, 2019). Yet, as Haglund & Eriksson first pointed out in 1993, the literature concerning possible risks of TBI in Olympic boxing is sparse and the results are inconsistent. Hence, it is difficult to compare results from the studies in the reviewed literature and draw conclusions based on it.

The studies that include headguards as a factor in injury prevention signal that the headguard has some protective capabilities. The boxing headguard provides substantial protection against skull fractures and cuts to the face and ears. In this context, McIntosh & Patton (2015a, 2015b) have argued that commercially available headgear is at best fulfilling a secondary injury risk management objective, preventing superficial head injury. Furthermore, the headguard provides some protection against linear impacts to the head (Beckwith, Chu, & Greenwald, 2007; Candy, Ma, McMahan, Farrell, & Mychasiuk, 2017). Some headguard models provide protection against neck injuries (Beckwith et al., 2007;

McIntosh & Patton, 2015b). However, these studies also demonstrate that current headguards provide less protection against rotational and angular impacts sustained from blows such as hooks, which arguably are dangerous impacts in terms of causing TBI in boxers (Bartsch, Benzel, Miele, Morr, & Prakash, 2012b). Studies that have tested headguard impact performance indicated that AIBA-approved headguards, in combination with AIBA-approved gloves (or even heavier padded gloves) will offer a high level of protection to the boxer's head (McIntosh & Patton, 2015a, 2015b).

4. Discussion

It is well known that boxing carries risk of sustaining both mild and traumatic head injuries (Coumoyer & Hoshizaki, 2019; McIntosh & Patton, 2015a). Systematic analysis of the literature shows that there is limited evidence to support the removal of headguards in elite men's boxing competitions. However, there is also limited evidence that weakens the decision to remove headguards. By this we mean that there is insufficient data on the protective effects headguards have on head injuries in elite and youth Olympic boxing. The reviewed literature shows that while headguards do protect against facial cuts and skulls fractures, less is known about the protective effect against concussions and other traumatic brain injuries. Hence, with the exception of cuts and skull fractures, we cannot for certain establish what the headguard does and does not protect against in terms of athlete injuries based on current research.

4.1. Does research support arguments for the headguard ban?

As we have outlined earlier, there is inadequate and insufficient data to determine if boxing with or without headguards is the safest in terms of preventing concussion and other head injuries. One of the main arguments for banning the headguard revolve around behavioural reasons. Here, AIBA's statement is that boxers will take more risks and "lead with the head" when boxing with a headguard, compared to boxing without a headguard (AIBA, 2015). The underlying reasoning of this argument is that wearing a headguard only provides psychological protection, but in reality puts boxers at increased risk of sustaining head injuries because wearing a headguard changes their behaviour. One study has investigated the impact the 2013 headguard ban has had on the behaviour of Olympic boxers. In their study, Davis et al. (2017) found that after 2013 rule change, boxers throw less punches and

land less punches. Furthermore, they discovered that defensive movement increased, and especially foot movement (moving away from the opponent) increased by 20% (Davis et al., 2017). In terms of head injuries, Davis et al. (2017) found that the number of standing counts was reduced from 9% pre-2013–3% post-2013. However, they also found an increase in knockouts and technical knockouts, from 1.7% pre-2013–4.2% post-2013 (Davis et al., 2017). Based on their findings, Davis et al. (2017) conclude, like the results from this systematic review does, that it is uncertain whether the removal of the headguard has led to an increased risk of concussive or traumatic brain injury post-2013. Yet, due to the changes in behaviour post-2013 Davis et al. (2017) concludes that it is likely that boxers believe that the headguard removal has made them more prone to knockouts.

Looking at research on risk-taking behaviour and protective headgear in other sports, AIBA's (2015) claims about changes in behaviour after the removal of the headguard could have some merit. In a study of skiing and snowboarding for example, wearing a helmet was associated with increased risk-taking behaviour, specifically in younger males (Willick et al., 2019). Phillips and colleagues showed that those who use helmets routinely perceive reduced risk when wearing a helmet, and compensate by cycling faster while cycling downhill (Phillips, Fyhri, & Sagberg, 2011). In a study by Bambach et al. (2013), non-helmeted cyclists were more likely to display risky riding behaviour, however, were less likely to cycle in risky areas; the net result of which was that they were more likely to be involved in more severe crashes (Bambach et al., 2013). As Willick et al. (2019) have found that increased risk-taking was especially associated with younger males, it might suggest that youth male boxers would be the athlete group to benefit from a headguard ban, as opposed to elite male boxers. This is further supported by a recent study on surfers' attitudes towards protective headgear by Dean and Bundon (2020), as their findings indicate that male athletes could be more negative towards protective headgear than female athletes.

In light of studies such as Willick et al. (2019), Follmer et al. (2020) and Dean and Bundon (2020), future studies on boxing and protective headgear should focus on behavioural changes, and the experiences and attitudes of athletes and coaches. As Steffen et al. (2010) argued in their ECSS position statement 2009 on the prevention of acute sports injuries: "[...] *true injury prevention can only be achieved if some form of behavioral change can be invoked in all individuals involved in an athlete's safety and health, including coach, referee, and the athlete him or herself*" (p.232). While Dickinson & Rempel's study

(2016) finds that 71.5% of their sample of 636 Canadian boxers and coaches oppose the rule change with the removal of the headguard, there is a need for similar studies of boxers and coaches in other countries.

4.2. A research agenda to address current gaps and limitations

There are prominent limitations and gaps in the primary evidence that can be addressed in future studies to improve the knowledge base for protective headgear and head injury prevention in Olympic boxing. Common limitations included indirect evidence, obtained through self-reporting or observational techniques with relatively small non-representative samples. Additionally, in most of the reviewed literature the focus is exclusively on male elite athlete: of 39 reviewed studies, only three include female boxers in their sample (Bianco et al., 2005; Dickinson & Rempel, 2016; Stojisih, Boitano, Wilhelm, & Bir, 2010). Subsequently, researchers should commit to include female boxers and youth boxers (both boys and girls) in their samples when investigating headguards and head injury prevention in Olympic boxing.

There are almost no randomised control trials (for an exception see Haglund & Erkiison, 1993), no longitudinal research designs (except from Loosemore et al., 2015b) and no direct measurement of injuries to the head, except from a study on rats (Candy et al., 2017). In most cases, no reference is made to other sport-related research on protective headgear and head injuries, such as for example, rugby, taekwondo, soccer, ice hockey (with the exception of Bartsch et al. (2012a) and McIntosh and Patton (2015b)). Furthermore, in the reviewed literature limited information is provided on the types of protective headgear (e.g. material, design, age), usage during contest and training, and interaction effects with other protective equipment such as the mouthguard and the function of retention systems. Considering these limitations, it is recommended that future studies focus on a combination of material properties that may increase impact attenuation and the ability of headguard to sustain several low-energy impacts. For example, O'Sullivan and Fife (2016) argued that "[...] *helmet geometry, padding type and thickness have all been shown to influence rotational acceleration*" (p. 2).

In our literature review, rapid rotational forces have been identified as a causative factor for severe brain injury. However, in their study on impact attenuation on commercially available headguards in boxing O'Sullivan and Fife (2016) argue that thicker headgear may not necessarily provide the best attenuative properties. Factors that are related to the design of soft-shelled

headgear, such as the use of auxetic materials, densities, external slip surfaces and honeycomb structures are yet to be extensively examined. Looking at the current state of the research, an urgent need can be identified for interdisciplinary research involving academics from the fields of engineering (e.g. design, material and mechanics), medicine (e.g. injuries, medical imaging) and social sciences (e.g. attitudes, experiences and behavioural aspects).

Another important element that surfaced from the review is that the question about headguard in boxing is too simplistic: “to wear or not wear”. However, what needs to be scrutinised more in-depth by epidemiological, field and laboratory research designs, which has been in other sports involving headguards (e.g. football, rugby) or leisure forms (e.g. cycling), is the fundamental question what “it” is. For example, the studies of Loosemore et al. (2007, 2015a) and Davis et al. (2017) do not refer to or discuss the types of headguard being worn (e.g. custom made or commercial; with or without chin and nose protection), the materials, the usage (e.g. multiple use or single use), the impact of the contextual factors (e.g. humidity and heat) on wearing the headguard and the interrelationship between (not) wearing a headguard during practices and competition. It seems that for the most part, in current studies, there exists only one type of headguard in boxing.

Additionally, the main voices that are currently missing from research are those of the boxers and boxing coaches. Except from Dickinson and Rempel (2016), no studies have investigated athletes’ attitudes towards headguards, and their opinion on the best safety measures for boxing. The same can be said about referees and other boxing officials. We further need to be vigilant about the fact that without exception, all studies have used (relatively small and non-representative) samples of competitive male boxers. To date, very little (to no) research exists on the headguard in the context of recreational boxing. The headguard might play another role in competitive boxing compared to recreative boxing and this should be subjected to further research. Together, these aspects represent substantial gaps in the current knowledge on boxing, headguards and head injury prevention.

5. Conclusion

The purpose of this article was to summarise and analyse existing research to establish what the headguard does and does not protect against in terms of athlete injuries, and if there are increased injury risks associated with headguard use. This systematic review concludes that while the headguard does protect against facial cuts

and skull fractures, there is insufficient data to conclude if removing the headguard in- or decreases the risk of concussion in boxing. As the current literature indicates that concussions and other head injuries are present in boxing with or without headguards, a possible strategy to protect the health and safety of the boxers might be to introduce regulations that lower the frequency and force of blows to the head. For instance through the development of a new boxing headguard that registers impact on the head, resulting in a maximum “impact dose” that automatically leads to termination of the match, as done in other Olympic sports such as fencing.

Our review has revealed that there is a striking need for further studies on boxing, headguards and head injury prevention. Based on the existing scientific literature, future research agendas should be concerned with addressing some of the weaknesses in the field that we have outlined in this review. Mainly: (1) larger samples and randomised control-group studies, (2) longitudinal research designs, (3) improved (direct) measurements of injuries to the head (e.g. in vivo (field-)research designs), (4) greater consideration for the type of headguards usage and material properties; (5) increased focus on female, youth and recreational boxers; and (6) social scientific studies that allow the boxers’ and coaches experiences to be heard.

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Data availability statement

Data are identifiable through Table 2 and the reference list. Since this is a review paper our empirical data consists of peer-reviewed research papers and can be accessed through the journals these papers have been published in.

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