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Headgear increases protection against acute concussion symptoms in amateur Olympic boxers
El casco aumenta la protección contra los síntomas de conmoción cerebral aguda en boxeadores olímpicos amateur

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Abstract. This study compared acute measures of concussion in Olympic boxers undergoing a combat. This is a case-control study where participants were measured in two conditions: a) using headgear (HG) and b) without using headgear (NHG). Thus, 14 athletes (24.9±5.1 yrs.; 77.1±13.9 kg; 1.7±0.1 m; 14.4±6.4 % body fat) completed this protocol. Tests were carried out before and after the combat (3 rounds of 3' with 1' interval) as indicators of concussion (BtrackS concussion test, automatic and controlled executive function, direct and indirect memory). A technical-tactical analysis protocol was also applied to verify the effect of HG on the actions during the combat. The HG condition showed better performance on the BtrackS concussion test (30.3±11.3 vs. 38.5±12.2; p=0.039), automatic executive function (38.0±6.0 vs. 50.4±11.4; p=0.014), and controlled (55.3±8.1 vs. 76.4±11.5; p=0.016). There was a significant difference in the number of punches connected to the head (38.5±12.0 vs. 51.1±14.7 for HG and NHG respectively; p=0.047). Based on our aims and the results obtained, our data support the acute protective effect of using HG in amateur Olympic male boxing against the concussion indicators.
Keywords: Combat sports, Boxing, Olympic Games, Brain concussion, Cognition, Sport rules

Resumen. Este estudio comparó medidas agudas de conmoción cerebral en boxeadores olímpicos sometidos a combate. Este es un estudio de caso-control donde los participantes fueron medidos en dos condiciones: a) usando casco (HG) y b) sin usar casco (NHG). Para esto, 14 deportistas (24,9±5,1 años; 77,1±13,9 kg; 1,7±0,1 m; 14,4±6,4 % grasa corporal) completaron este protocolo de investigación. Se realizaron las siguientes pruebas antes y después de un combate (3 rounds de 3' con intervalo de 1') como indicadores de conmoción cerebral utilizando las siguientes pruebas: test de conmoción cerebral BtrackS, función ejecutiva automática y controlada y memoria directa e indirecta. También se aplicó un protocolo de análisis técnico-táctico para verificar el efecto del HG en las acciones durante el combate. La condición HG mostró mejor desempeño en la prueba de conmoción cerebral BtrackS (30,3±11,3 vs. 38,5±12,2; p=0,039), función ejecutiva automática (38,0±6,0 vs. 50,4±11,4; p=0,014) y controlada (55,3±8,1 vs. 76,4±11,5; p=0,016). Hubo una diferencia significativa en el número de golpes conectados a la cabeza (38,5±12,0 vs. 51,1±14,7 para HG y NHG respectivamente; p=0,047). Con base en nuestros objetivos y los resultados obtenidos, nuestros datos respaldan el efecto protector agudo del uso de HG en el boxeo olímpico masculino amateur contra los indicadores de conmoción cerebral.
Palabras clave: Deportes de combate, Boxeo, Juegos Olímpicos, Conmoción encefálica, Cognición, Reglas deportivas.

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Introduction

Olympic boxing is a combat sport where the athlete throws punches above the waist line to beat the opponent and achieve victory (Gutiérrez-Santiago et al., 2023; Puchol et al., 2023). In this context, one of the most effective strategies during combat are punches to the head (Dunn et al., 2017; Slimani et al., 2017). According to Dunn et al. (2017), winners show a higher precision when it comes to blows targeted to the head (33 vs. 23% of effectivity). Given its importance for victory, the head punch represents at least 80% of the total number of blows, with a frequency of ≥30 blows in beginners and ≥50 in elite athletes per round (Slimani et al., 2017). However, these punches can put fighters' health at risk, as the high frequency of blows connected to the head increases the risk of concussion, whether in professional or amateur athletes (Donnelly et al., 2023).

Concussion is a traumatic brain injury that occurs due to the impact of biomechanical forces on the head, resulting in temporary or permanent damage (Alevras et al., 2022; Harmon et al., 2013). Due to the risk inherent to the sport, the International Boxing Association (IBA) implemented guidelines to minimize risks and ensure the safety of athletes. These guidelines include medical examinations and neuropsychological assessments before competitions, modifications to rules and protective equipment, and medical evaluation during and after bouts (Davis et al., 2018). These preventive strategies may reduce the incidence and severity of concussion in boxers (Davis et al., 2018). However, epidemiological studies show a higher concussion incidence in boxing compared to other combat sports (Bernick et al., 2021; Bromley et al., 2018; Lystad, 2015). This fact is alarming, as repeated concussions can increase the risk of chronic neurological diseases such as Alzheimer's, Parkinson's and other dementias (Gallo et al., 2020). In this context, it is relevant to investigate whether or not competitive norms can increase the risk of concussion in boxers (Davis et al., 2018).

When analyzing the context of boxing at the Olympic Games, headgear (HG) was inserted in 1984 (Los Angeles) to avoid cuts to the face and bleeding; however, from 2013

onwards, the IBA removed the use of HG for male competition (Tjønndal et al., 2022). The use of this equipment has associated risks and benefits; among the favorable arguments, we can mention additional protection against bruises, reduced risk of cuts and superficial injuries (McIntosh & Patton, 2015a; Schneider et al., 2017). On the other hand, HG can create a false sense of security, and so fighters accept more blows relying on its absorptive capacity and increase the risk of cervical injuries due to the increased weight on their head (Loosemore et al., 2017; Lystad, 2015).

The removal of HG raises concerns among the scientific community, coaches and athletes (Tjønndal et al., 2022). The consensus issued by the Canadian boxing community strongly opposes the removal of HG (Dickinson & Rempel, 2016). One of the concerns is associated with the longevity of the career and also the quality of life of fighters after their lives as athletes, since diseases developed by successive concussions (e.g. Parkinson's disease) tend to manifest themselves late (Bleiberg et al., 2004; deWeber et al., 2023). However, there are arguments against HG, as it makes combat more dynamic, Loosemore et al. (2017) state in their cross-sectional study that the removal of HG resulted in fewer interruptions in competitions promoted by the IBA. In this uncertain environment, the Association of Ringside Physicians recommends that further studies be carried out to verify whether there is greater protection or risk associated with the use of headgear (deWeber et al., 2023). In our search for investigations we found systematic reviews which analyzed epidemiological studies of concussion (Bromley et al., 2018) and studies analyzing chronic symptoms in athletes and former athletes (Donnelly et al., 2023; Manley et al., 2017). However, to the best of our knowledge, few studies directly compare combat with or without HG. We believe that this type of study can contribute to knowledge about the concussion risk associated with boxing. Based on the above, the present study aimed to compare acute measures indicative of concussion in amateur boxers submitted to a bout within Olympic rules through a paired case-control protocol where combat with and without HG were compared. We hypothesize that combat carried out with HG will increase the protective effect on balance and result in lower cognitive and memory impairment.

Materials and methods

Experimental approach

The present protocol was approved by the Research Ethics Committee of the University where the data were collected (no. 71430923.4.0000.5546). A researcher initially contacted two boxing teams in the city (RZ and Baloutta Team) and presented the study proposal to the coaches. After consent, the fighters who met the inclusion criteria were invited to participate. Those who agreed to participate voluntarily signed the Informed Consent Form. The present experimental protocol was carried out on 3 different days. On the 1st, a sociodemographic analysis was conducted (intelligence test, education, training time for competition, hours and frequency of weekly training, weight division, sparring sessions/week, concussion symptoms and medication use) and anthropometry. The participants were separated by weight division (in the absence of a pair in the same division, the fighters were matched with an athlete of another division, as long as the difference did not exceed 5kg). Half of the paired matches were randomized drawn to be performed in NHG condition on the second day of data collection, with the others were performed with HG condition. The conditions (HG vs. NHG) were reversed on the 3rd day.

Combat protocol

The present experimental protocol was based on a previous study carried out by Rydzik et al. (2023) in kickboxing athletes. The bouts in both conditions (HG or NHG) were carried out following the rules of Olympic boxing (3 rounds of 3 minutes with a 1-minute interval; the bout could be ended early in the event of a knockout or technical knockout). Tests were conducted prior to and immediately after the bout to measure cerebral concussion indicators (one physical test and two neuropsychological questionnaires). Regardless of the condition, a standardized warm-up was performed consisting of the following items: 5 minutes of stretching, 5 minutes of aerobic exercises and 5 minutes of free gauntlet. Figure 1 presents the experimental design.

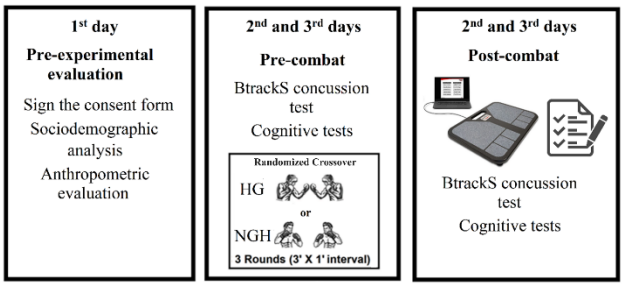

Figure 1. Chart of the complete experimental protocol.

Participants

A total of 20 Olympic amateur boxers were invited to participate in the present study. The following inclusion criteria were adopted: a) ≥18 years of age.; b) ≥ 2 years of experience in boxing competition; c) be training for competition; d) not present any physical impairment that would affect the boxing performance; and e) be authorized by the coach. The exclusion criteria were: a) fighters who competed ≤14 days ago; b) participants who were injured during any experimental and were unable to perform all measurements; c) those who wished to withdraw from the study.

The sample size calculation was estimated based on a previous study that compared fighting with HG and fighting without HG in kick boxing athletes (Rydzik et al., 2023) and a concussion study using the BTrackS scale (Goble et al., 2016). The BTrackS concussion test was considered the

main variable for estimating the sample size. According to the Granmo 7.12 software program (IMIM, Barcelona, Spain), 13 participants per condition were needed to estimate the sample size with reliability of 95% and accuracy close to 20% (replacement percentage required of 5%). Of the total number of invited, 15 were included and started the study, one participant suffered a knockout (NHG condition) and was unable to participate in all measurements. Thus, the final sample of the present study was composed of 14 amateur boxing athletes (24.9±5.1 yrs.; 77.1±13.9 kg; 1.7±0.1 m; 14.4±6.4% body fat), all participants performed the combat in two conditions (HG and NHG). Of total, (age: 24.9±5.1 yrs.; BM: 77.1±13.9 kg; HT: 1.7±0.1 m; 14.4±6.4% body fat). Of the total; 77.8% declared to be right-hand dominant; 55.6% trained at least 3x a week and competed in boxing for at least a year; and 44.5% perform sparring sessions at least 2 times/wk. All participants estimated that they received at least 20 punches to the head/wk. Regarding previous symptoms of concussion, 55.6% said they had felt a headache and 22.2% dizziness as a result of a blow to the head. In relation to baseline intelligence characteristics, 27.3% did not present any type of cognitive impairment, 54.5% were classified as average and 18.2% low cognitive impairment. The baseline cognitive tests to characterize the sample were applied following the methodology described by Tosi (2019). The baseline characteristics of intelligence and cognition were used as covariates to analyze automatic, controlled, direct and indirect memory processes.

Anthropometric measurements

The anthropometric evaluation was conducted in accordance with the recommendations of Lohman et al. (1988). Body mass was measured on a scale with precision of 100-g (Lider P-150M®, São Paulo, Brazil). A portable stadiometer was used to measure height with an accuracy of 1 cm (Auturexata®, São Paulo, Brazil). Body density was estimated using the Lohman (2002) equation for wrestlers. Body composition was estimated by the Brožek et al. (1963) equation.

BTrackS concussion test

The validated protocol for the BTrackS scale was applied (Balance Tracking Systems Inc., San Diego, USA) to estimate possible damage caused by cerebral concussion. The test consisted of four 20-s trials with short intertrial intervals (<10 s), which began and ended with a sound signal. The first attempt was used for familiarization and the remaining 3 were computed by the software (BTrackS Sport Balance software, Balance Tracking Systems Inc., San Diego, USA). The participant should remain as still as possible with their eyes closed, hands on their hips and feet shoulder-width apart during the test. This protocol has 64% sensitivity and 90% specificity for diagnosing concussion (Goble et al., 2016). The estimation of concussion risk is the result of the average displacement of the center of pressure for the x and y axes. Thus, the smaller the displacement, the lower the concussion risk.

Assessment of executive functions

The five-digit test was used to estimate executive functions according to procedures described by Campos et al. (2016). The first two stages of the test are considered tasks which involve more automatic attention processing (wakefulness and orientation attentional networks), requiring only the reading of the numbers from 1 to 5 and the perceived of quantities between one and five, primarily depending on the processing speed. The third and fourth part of the test involve controlled attention processes (executive-attention network). The test consists of four stages: reading, counting, choosing and alternating, generating scores based on the execution times in different stages: measures of automatic attention, processing speed, controlled attention and executive attention. This test was applied by a psychologist. Scores were calculated for automatic and controlled processes, in which the higher the score, the worse the result.

Memory test

As an estimate of working memory capacity, the Digit span test was used according to the procedures described by Nascimento (2004). This test consists of two parts. Digits are initially administered in order and require repeating the digits in the same sequence. Then, the digits are presented inverted and the person being evaluated must repeat in reverse order. This test is used to measure the number storage capacity of working memory. After each successful attempt, it increases by one digit to increase the difficulty. Direct and indirect memory scores were calculated. The greater the number of digits memorized and reproduced, the better the score.

Combat performance evaluation

All combats were recorded using a mobile phone (iPhone 14 Pro®, Apple Inc, Cupertino, USA) to verify possible differences between the intensity of the bouts in the two experimental conditions, and then by analysis in the Frami software program using the time and time-motion protocol for boxing proposed and validated by Lima et al. (2022). The following frequencies of actions were analyzed for the present study: a) displacement; b) defense; c) clinch; d) total number of attacks connected on the body; e) total number of blows connected to the head; and f) pause. All variables presented an intraclass correlation coefficient ≥0.9.

Statistical analyzes

The data were initially tabulated in contingency Tables and the Shapiro-Wilk test was performed to verify the normality of the sample. When normality assumptions were achieved, comparison between groups was performed by two-way ANOVA (condition X time). The Kruskal-Wallis test was performed when appropriate. Finally, $p \leq 0.05$ was adopted and tests were carried out using the SPSS version 22.0 software program for all analyzes.

Results

The results regarding significant differences will be presented by [median (1st; 3rd quartile). There was a significant interaction between the measurement moment (i.e.; Pre and Post combat) and the two combat conditions ($F_{1,13}$= 4,639; p=0.039; ηp^2=0.114) for the Btracks concussion test, where the means observed for HG were statistically lower when compared to the NHG condition in the post moment [8.3 (0.4; 17.0) a.u.; p=0.003]. Figure 2 shows the distribution of scores for both conditions before and after the combat.

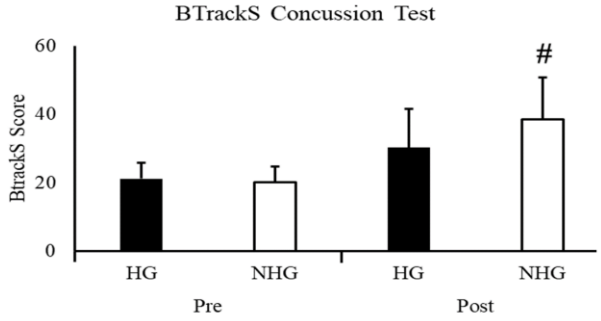

Figure 2. Results for BtrackS concussion test. # p=0.036 vs. With headgear (HG).

Regarding automatic executive function, there was an interaction effect between the condition and the measurement moment ($F_{1,13}$= 6.901; p=0.014; ηp^2=0.21), where the NHG condition presented a higher mean in the post-combat moment [12.4 (5.3; 19.5) sec.; p=0.001]. Similar results were observed for controlled executive function ($F_{1,13}$= 6.65; p=0.016; ηp^2=0.204). The NHG condition also presented higher means in the post-combat moment for this variable [21.1 (13.4; 28.8) sec.; p≤0.001]. There was no significant difference for the measurement moment ($F_{1,13}$= 1.002; p=0.329; ηp^2=0.048) for direct memory, and there was no interaction effect ($F_{1,13}$= 0.671; p=0.423; ηp^2=0.032). Similar results were observed for indirect memory, where no effect of measurement moment was observed ($F_{1,13}$= 0.702; p=0.412; ηp^2=0.034), or interaction effect ($F_{1,13}$= 0.044; p=0.836; ηp^2=0.002). The results for the executive function and memory test are presented in Table 1.

Table 1.
Results for the executive function and memory test for the HG and NHG conditions.

Condition	HG		NHG	
Measurement moment	Pre	Post	Pre	Post
Automatic Process (sec.)	42.9±6.9	38.0±6.0*	43.0±7.3	50.4±11.4
Controlled process (sec.)	71.3±17.8	55.3±8.1*	73.1±16.9	76.4±11.5
Direct memory (a.u.)	10.0±1.9	10.0±2.4	10.2±1.8	10.3±2.0
Indirect memory (a.u.)	4.8±2.4	4.7±1.9	4.7±1.2	4.4±1.5

HG – Headgear condition, NHG – No-Headgear Condition. a.u. – arbitrary units. * Significant difference p≤0.0.01 versus NHG at the post-combat moment.

Table 2 shows the frequencies of technical-tactical actions for the two combat conditions. There were no significant differences for the actions of displacement, attack, defense, clinch and pause (p≥0.05); however, there was a significant difference for the number of blows connected to the head ($T_{1;13}$=2.437; p=0.047; d'=0.23) and pause ($U_{1;13}$= 902.5; p=0.029).

Table 2.
Frequency of displacement, attack, defense, clinch and pause actions for the HG and NHG conditions.

Technical-tactical actions	HG	NHG
Displacement	57.9±11.0	54.3±16.2
Attacks	62.8±22.0	62.8±27.8
Attacks received to the head	51.1±14.7#	38.5±12.0
Defense	46.6±21.7	42.2±22.0
Clinch*	0.4±0.8	0.4±0.7
Pause*	3.0±2.4#	2.2±1.8

HG – Headgear condition, NHG – No-Headgear Condition. * Comparison carried out using the Kruskal-Wallis test. # p≤0.047 vs. NHG.

Discussion

Boxing has a low overall injury rate but a high rate of head injuries, unlike disciplines such as taekwondo and karate. It is estimated that one injury occurs every 2.5 h of competition, or 722 h of training, but the highest number of injuries occurs to the head (Alevras et al., 2022). According to the meta-analysis performed by Donnelly et al. (2023), boxing presents a higher concussion risk than other combat sports (risk ratio: 0.253 vs. 0.065); in addition, ≈30% of amateur boxers showed brain atrophy, ≈61% demonstrate symptoms of dementia and ≈51% present cognitive disorders. In this competitive context which increases the risk of health, there are favorable (deWeber et al., 2023; Dickinson & Rempel, 2016) and unfavorable statements (Bartsch et al., 2012; Loosemore et al., 2017) for using HG. According to Tjønndal et al. (2022), it is not clear whether or not HG can protect or increase the risk of concussion in boxers, therefore further studies are needed to provide more certainty regarding the protective effect of HG. In turn, the present study compared the acute effects on concussion in amateur boxers comparing HG and NHG conditions through a randomized case-control protocol. The main results indicated that HG has a higher protective effect, as this condition resulted in lower scores on the BtrackS concussion test and lower cognitive impairment regarding automatic and controlled processes. There were no differences regarding technical-tactical analysis between the number of blows performed, however more blows were connected to the head in the HG condition.

The BtrackS protocol for concussion is based on maintaining balance, therefore a higher displacement on the scale represents an increased risk (Goble et al., 2016). This is a direct, easily applied, low-cost test (Hearn et al., 2018), has high sensitivity (Goble et al., 2016; Goble et al., 2019), was widely applied to athletes aged 8-21 years (Goble et al., 2019) and was used to evaluate the risk of concussion in adult female football athletes (Rhea et al., 2019). We are not aware of the existence of studies in combat sports that have used the BtrackS protocol. Due to its ease and speed,

it becomes an interesting test for tracking concussion in athletes (Benedict et al., 2017). Furthermore, previous studies have shown that the protocol has high reproducibility (Hearn et al., 2018). Another interesting advantage of this test is a lower influence of fatigue as a confounding variable. According to Benedict et al. (2017), if the test is carried out 5 minutes after exercise, there will be no influence of fatigue on the result. Our data showed that the HG condition was more stable after a combat, showing a lower effect of combat actions on concussion.

It is interesting to note that the participants in the HG condition suffered more blows to the head (Table 2). Thus, our results reinforce previous studies that demonstrate the absorptive capacity of HG (McIntosh & Patton, 2015a, 2015b), especially if they are composed of expanded polystyrene (Razaghi et al., 2018). It is speculated that the higher number of blows received by athletes with the HG condition is associated with impairment in the field of vision. According to the IBA, one of the reasons for removing HG is associated with the affected field of vision, which makes it difficult the dodge actions (Tjønndal et al., 2022). In addition to the connected punches, there were significantly more pause actions during the HG combat condition. According to Slimani et al. (2017), amateur boxing bouts are characterized by high-intensity periods with short duration, followed by pause moments, which are caused by the athletes through clinching actions; however, our data do not show differences in the frequency of clinches. Thus, a limitation in our study was not controlling the bout intensity, which could be the target of future studies. We are unaware of any studies which have directly measured this effect in boxing, but analyzes carried out with HG in American Football players (Miller et al., 2019) and skiers (Očić et al., 2023) showed that the influence on the visual field is insignificant. Future studies could examine whether or not boxing-specific HG impairs athletes' vision.

Previous studies have shown that boxers who suffer a concussion have impaired cognitive capacity (Gallo et al., 2020). Executive functions are the most complex of human cognition, as they are closely linked to our ability to focus on our goals, modulating our ability to plan and regulate the emotional processes (Jacobson & Matthaeus, 2014). Despite our acute results, Bleiberg et al. (2004) observed that worsening cognitive function lasts up to 7-days after concussion. Stiller et al. (2014) observed an indirect association between the amount of sparring performed by professional boxers and their performance on cognitive tests. On the other hand, in a study which followed amateur boxers for 7-days, Moriarity et al. (2004) observed that the boxing competition only affects cognition when the fighter is knocked out. It is interesting to highlight that the only study to not observe worsening cognition was carried out in boxers who competed with HG.

Our results indicated acute worsening of automatic and controlled executive function in the NHG condition. Automatic executive functions are related to the habits that we perform more frequently due to training, and controlled functions refer to the responses against new situations(Furley et al., 2015). In this context, the worsening of executive functions can affect a fighter's performance, as they may present difficulty in performing techniques which they have extensively trained, as well as putting themselves in difficulty when faced with a fighter who has different technical-tactical actions.

When observing the post-combat moment, the NHG spent on average ≈11 seconds longer to complete the tests related to automatic and controlled processes compared to the HG at the same moment of measurement. We believe that the blows suffered to the unprotected head were the main factor contributing to the worse performance. It is possible that post-fight fatigue also played a role. In fact, studies have shown that exhaustive exercise negatively impacts cognitive capacity (Sudo et al., 2017; Zimmer et al., 2017). However, we believe that, if this influence occurred, it was minimal, as the HG condition presented a higher frequency of pauses during combat, although the other technical-tactical actions indicated similar intensity in both conditions (Table 2).

Unlike other cognitive measures, there was no acute impairment to the fighters' direct and indirect memory. We are unaware of protocols that compared bouts with or without HG and the effect on memory. Our results partially corroborate those observed by Stojsih et al. (2010), where they did not observe an acute effect of sparring on verbal memory, but it did affect delayed memory (difficulty retaining information). In comparison to previously published papers, it is clear that the negative effects of concussion on memory were observed in chronic studies. Analysis of amateur boxers (Herweh et al., 2016) and former boxers (Wilde et al., 2016) indicated that fighters who have preserved white matter have less memory deterioration. In this context, one can also mention the number of connected blows, history of concussion (Doan et al., 2022) and the amount of sparring performed as factors which affect attention, concentration and memory (Jordan et al., 1996). The results of the present study must be interpreted in light of the limitations and delimitations of the present protocol as our data were obtained in amateur fighters, of which ≈50% already presented mild symptoms of concussion and demonstrated deterioration in cognitive capacity. Therefore, it is important to emphasize that athletes without cognitive impairment may present better results when subjected to a NHG combat. Furthermore, the present study applied an acute protocol, however, the most severe symptoms of concussions occur late. (Alevras et al., 2022; Donnelly et al., 2023; Gallo et al., 2020). So, it is interesting that new protocols investigate whether boxers chronically exposed to NHG combat present worsening of cognition.

Care must be taken when making associations regarding the protective effect of HG in different types of combat striking. According to Arriaza et al. (2017), there is low concussion incidence in Karate competition, despite the

sport being performed without HG; it is not allowed to knock out the opponent, thus minimizing the impact of attacks to the head. Future protocols which may include women and professional athletes, may or may not confirm the data obtained herein. As a suggestion for practical application, coaches can use the results of this study to protect athletes from risk exposure. Studies have shown that fighters have difficulty recognizing symptoms of concussion or when they recognize they refuse to stop training (Bartsch et al., 2012; Tjønndal et al., 2022). Considering that Olympic boxing matches are performed without HG, coaches can reduce the frequency of sparring sessions, conduct sparring with HG and leave NHG training for periods close to the competition.

Conclusion

According to our aims and results, we can conclude that an Olympic boxing match performed using HG results in a higher protective effect against concussion, as lower scores were observed in the BtrackS concussion test and lower cognitive impairment regarding automatic and controlled processes. The results can be applied by coaches, athletes and physicians to include the use of HG in their training routines.

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