Rotational Acceleration in Traumatic Brain Injuries (TBI) Related to Combat Sports: A Systematic Review

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Abstract

Introduction: Considering the importance of rotational acceleration in causing traumatic brain injuries and also the possibility of its greater risk in combat sports, this systematic review study investigated the rotational acceleration produced in head brcase of combat sports in different blows and compared it with the threshold of traumatic brain injuries(TBI). **Materials and Methods:** In this study, articles were searched in Web of Science, Scopus, PubMed and Persian databases. 23 related articles were selected based on inclusion and exclusion criteria. **Results:** Findings showed that the highest rotational acceleration produced in head first was due to the hook impact in boxing without a headgear (11279.5 rad/s2) and second, the spinning kick in taekwondo with a headgear (rad/s2 10927). Hook kick in taekwondo (rad/s2 9756), direct punch in taekwondo (rad/s2 9556) and roundhouse kick in taekwondo (rad/s2 8703) were in the next ranks, respectively. Comparing these accelerations with the threshold of TBI, hook kick in boxing and spinning kick in taekwondo can lead to concussion and severe brain axonal damage, but hook kick, direct punch and roundhouse kick in taekwondo may cause only to concussion. **Conclusion:** protective headgears in combat sports cannot significantly reduce the speed of rotation and this issue can even increase the rotation acceleration in some sports such as boxing. Therefore, it is suggested that those in charge of this matter and headgear manufacturing companies should pay special attention to this point and take an important step in reducing TBI injuries by re-examining the design of headgears.

Keywords: Acceleration; Brain Concussion; Martial Arts; Traumatic

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Introduction

Traumatic Brain Injury (TBI) occurs when an impact or external mechanical force is applied to head and causes disruption in brain function (1). Concussion, diffuse axonal injury and acute subdural hematoma (SDH) are examples of TBI which can be mild, moderate or severe. It has different clinical symptoms in TBI, from decreasing consciousness level to complete amnesia, and also associated with changes in mental status (such as confusion) and focal neurological deficits (2). Most athletes will completely recover after one week of TBI, however, some evidences show prolong neurological effects such as recurrent headache, cognitive impairment and death (1).

TBIs are common in martial or combat sports and diagnosed approximately 300000 cases per year (3). Combat sports generally have the nature of striking (such as: boxing and taekwondo) or grappling (such as: judo and wrestling) or a combination of both (such as: mixed martial arts (MMA)) (4).Therefore TBI can be occur as a result of direct blows to head or after being thrown and falling down. The sudden increase and decrease of acceleration caused by struck results to severe movements of the brain inside the skull and leads to extensive neurovascular injuries. Regarding the head movement relative to the body, acceleration can be linear or rotational (5). Although both might occur, rotational acceleration, is more significant in causing TBI. Brain tissue tends to deform following the application of shear forces, and

approximately 90% of the total shear stresses produced can be attributed to rotational acceleration (6).

The linear acceleration leads to local injury and the rotational acceleration leads to diffuse brain injury. Although linear acceleration has been used to improve the design and performance of martial arts headgear, but a low correlation between martial arts headgear and the prediction of brain damage have been reported. Most of the blows to the head in combat sports cause a head rotation in addition to transmission movement. The linear acceleration is often tolerated or neutralized by the strength of neck muscles. So, the researchers stated that the injuries caused by linear acceleration will be decreased by strengthening the neck muscles (7). However, the head rotation resulting from the impact, by making rotational acceleration, may cause shear stress between the brain and the connective tissue of skull and as a result, lead to the spread of axonal damage and vascular structures (8).

TBIs cause problems due to lack of simple diagnostic methods and the absence of visible identification signs when they occur (9). Confusion about its timely diagnosis leads to inconsistent management, and with the untimely returning of the athletes to sports fields, the risk of TBI will increases further (9, 10). Thresholds of TBI caused by head rotational acceleration are different in different combat sport, for example the threshold of concussion damage is 4500rad/s^2, but the: Acute subdural haematoma (ASDH) is 10000 rad/s^2 (11, 12). Knowing the rotational acceleration created in head in different combat sport can provide specialists with great help in providing appropriate and therapeutic solutions.

Therefore, considering the importance of rotational acceleration in causing TBI and also the possibility of its greater risk in combat sports, this study aims to investigate the rotational acceleration produced in head in combat sports in different blows and compare it in a review study deals with the threshold of TBIs.

Materials and Methods

In this systematic review, Web of Science, Scopus, PubMed and Persian language databases such as Comprehensive Medical Articles Database, Comprehensive Humanities Portal, Health Articles Database, Islamic World Science Reference Database, Academic Jihad Scientific Database, Journal System Iranian science and the country's publications database were searched separately. Google Scholar academic search engine was used too. The search terms were combined with them like; Head Injury, Brain Injury, Rotational Acceleration of head and Traumatic Brain Injury and used in databases Searches were conducted between 2005 and 2023. The inclusion criteria included as: a) original articles; b) Articles with a research sample derived from the statistical community of combat athletes, c) boxing- based articles, taekwondo, karate, kickboxing, wrestling, judo and Mixed Martial Arts (MMA).

Exclusion criteria of study included as: a) non-English and non-Persian articles; b) case report, commentaries, comments following the articles, narrative reports, and news and letters, c) articles published in the blacklisted journals. Studies that exclusively measured linear acceleration or any other kinematic variable that didn't include rotational acceleration were also excluded. A total of 445 articles were obtained from the searches in all databases. Among these, 152 articles were suitable in terms of title and abstract, and 70 articles were selected after removing duplicates and screening those that did not meet the inclusion criteria. Finally, 23 articles were included for review in the present study (Figure 1).

Result

The present study reviewed the articles related to rotational acceleration in TBIs in combat sports. By checking the Persian and English databases, 23 studies were reviewed based on research inclusion criteria. The studies' information including the authors' names, the publication year, the country under study, the research methodology, technique type, sports field, use or non-use headgear, rotational acceleration and threshold of TBI are provided in Table 1. Among the reviewed studies, 9 studies from America, 5 studies from Japan, and 2 others, each from Korea and Ireland, were included. One study was related to Australia and one to Canada. Also, 3 studies from Iran were found too. These studies were related to boxing, judo, taekwondo, wrestling and MMA. In this study, the methods of data collection were either through human dummy, or through the use of human dummy along with athlete, or mechanical dummy. Computer simulation methods were also used.

Boxing: Among the researches related to rotational acceleration in TBIs, 11 studies were conducted on boxing. 9 of the rotational accelerations produced in head are caused by a direct punch, 3 of them are from a hook punch and 1 is from an uppercut. Considering the review of previous searches, the rotational acceleration range created in direct straight punch is between 1530 rad/s^2to14065 rad/s^2 in the hook punch between 1740$rad/s^2$1740to 11279/5$rad/s^2$and in uppercut is 3181 rad/s^2. In 5 of the methods of evaluating these accelerations a mechanical device was used, in 3 of them human dummy and athletes, in 2 of them human dummy and in one of them simulation was used too. Except in 4 studies, headgears were used in the rest of them.

Table1. Study characteristics and outcomes

Authors	Country	Method	Technique	Sport	Use of headgear Yes/no	Rotational acceleration *Rad/s²*	Concussion injury threshold 4500 *Rad/s²*	Damage threshold DAI, ASDH 10000 *Rad/s²*
Boroushak *et al.* (14)	Iran	Computer simulation	Straight punch	Boxing	No	4036	No	**No**
Doan *et al.* (25)	USA	Human and Dummy	Straight punch	Boxing	Yes	1647	No	**No**
Jansen *et al.* (29)	USA	Human and Dummy	Straight punch Roundhouse kick	Boxing MMA	Yes	3773 1766	No No	**No** **No**
Murayama *et al.* (19)	Japan	Human and Dummy	Osoto-gari	Judo	No	679/4	No	**No**
Murayama *et al.* (20)	Japan	Human and Dummy	Seoi-nage	Judo	No	1890/1	No	**No**
Tiernan *et al.* (33)	Ireland	Human and Dummy	Roundhouse kick	MMA	No	7069/5 (max)	Yes	**No**
Tiernan *et al.* (34)	Ireland	Human and Dummy	Straight punch	MMA	No	5169 (max)	Yes	**No**
Boroushak et al, (15)	Iran	Mechanical Device	Roundhouse kick	Taekwondo	No	4656/22	Yes	**No**
Cournoyer *et al.* (24)	Canada	Mechanical Device	Hook	Boxing	No	11279/5	Yes	**Yes**
Boroushak *et al.* (13)	Iran	Computer simulation	Roundhouse kick	Taekwondo	Yes	5908	No	**No**
Fife *et al.* (26)	USA	Human and Dummy	Hook kick Turning kick Straight punch	Taekwondo	Yes	9756 10927 9556	Yes	**No**
Ishikawa *et al.* (35)	Japan	Human and Dummy	1)Osoto-gari 2) Ouchi-gari	Judo	Yes	693/2 401/6	No	**No**
O'Sullivan *et al.* (31)	Korea	Human and Dummy	Roundhouse kick	taekwondo	Yes	4455 (max)	No	**No**
O'Sullivan *et al.* (30)	Korea	Mechanical Dummy	Straight punch Roundhouse kick	Boxing taekwondo	Yes	14065 28703	Yes Yes	**Yes** **No**
Hecimovich *et al.* (27)	USA	Human and Dummy	grappling	Wrestling	Yes	1698/8	No	**No**
McIntosh *et al.* (18)	Australia	Mechanical Device	Straight punch	Boxing	Yes	4335	Yes	**No**
Murayama *et al.* (21)	Japan	Human and Dummy	Osoto-gari	Judo	No	4572/6	No	**No**
Hitosugi *et al.* (28)	Japan	Human and Dummy	1) Osoto-gari 2) Ouchi-gari	Judo	No	3315 1328	No	**No**
Bartsch *et al.* (22)	USA	Mechanical Device	Hook	Boxing MMA	Yes	1740 5550	Yes	**No**
Stojsih *et al.* (32)	USA	Human and Dummy	Straight punch	Boxing	Yes	2307 (max)	No	**No**
Beckwith *et al.* (23)	USA	Mechanical Device	Straight punch	Boxing	No	1530	No	**No**
Viano *et al.* (17)	USA	Human and Dummy	1) Straight punch 2) Uppercut punch 3) Hook punch	Boxing	No	5452 9306 3181	Yes Yes No	**No** **No** **No**
Walilko et al, (16)	USA	Human and Dummy	Straight punch	Boxing	Yes	6344	Yes	**No**

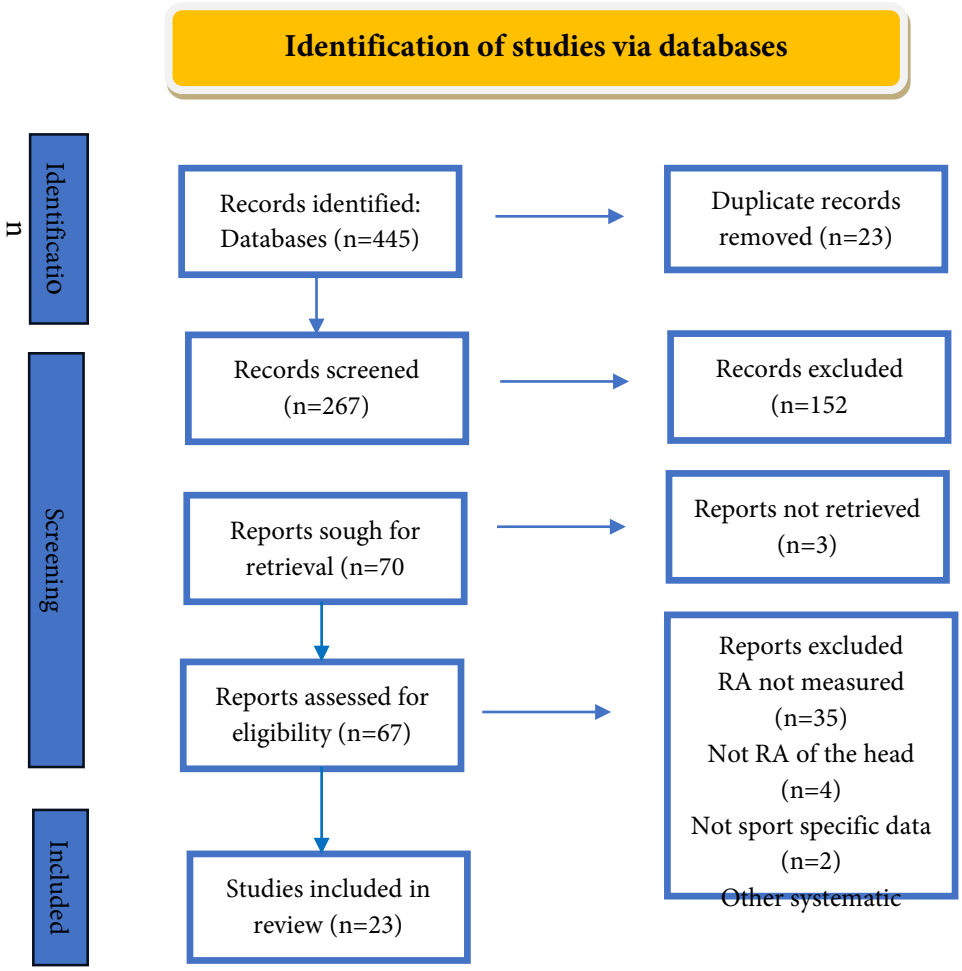

Figure 1. Flow chart of study selection process

Taekwondo: By reviewing past researches, 5 studies were found on Taekwondo. The rotational accelerations of head in 4 cases were caused by the roundhouse kick. Also, in other studies, it was shown that the rotational acceleration produced can be caused by hook kick, rotating kick and direct punch, which 1 case was found for each kick. The ranges of theses accelerations are: for round house kick between 4346 rad/s^2 to 8703 rad/s^2, for the hook kick 9756 rad/s^2, for the rotating kick 10927 rad/s^2, and for the direct punch.9556 rad/s^2. In the methods of evaluating these accelerations of 3 studies a mechanical dummy was used, in 1 study, simulation, and in 1 other study an athlete and human dummy were used. It should be mentioned that in 3 studies headgears were not used.

MMA: There were 4 researches related to MMA. Two of these studies found in round house kick, however, in hook kicks and straight punches found 1 case for each. The range of accelerations in roundhouse kick was between 1766 rad/s2 and 7069/5 rad/s2 and in hook and direct punch 5550 rad/s^2 and 5169 rad/s^2, respectively, and in 2 cases of the studies headgear was not used. For evaluation method, athlete and human dummy and in 1 case just a mechanical dummy was used.

Judo: By reviewing past research, 4 studies were found on Judo. Rotational accelerations of head in 3 studies were caused by Osoto-gari impact, in 1 study by Ouchi -gari impact, and in another study by Seoi-nage impact. The range of these accelerations was between 679.4 rad/s2 and 4572.6 rad/s2 in Osoto-gari. Also, it was 1328 rad/s2 for Ouchi -gari impact and 1890/1 rad/s2 for Seoi-nage impact. In methods of evaluating these accelerations of 2 studies, athletes and human dummy and in the other 2 studies just human dummy were used. No headgear was used in study.

Wrestling: From the conducted researches, 1 study was found in wrestling and caused by grappling. The rotational acceleration due to the impact was 1698.8 rad/s^2. In the acceleration evaluation method of this study an athlete and a human dummy was used.

Discussion

The purpose of this systematic review study was the investigation of the rotational acceleration in TBIs related to combat sports. In this regard, articles were searched in English and Persian databases and the articles which were found in boxing, taekwondo, MMA, boxing and judo were selected based on the inclusion and exclusion criteria, then were analyzed.

Traumatic Brain Injuries (TBIs)

By reviewing the researches, it was found that the highest rotational acceleration of head was due to the hook impact (11279/5 rad/s^2) in the condition of without a headgear and in the field of boxing. The rotation kicks in taekwondo (10927 rad/s^2) showed the highest acceleration in head in the condition of wearing the headgear. The hook kicks in Taekwondo (9756 rad/s^2), the straight punch in taekwondo (9556 rad/s^2) and the roundhouse kick in Taekwondo (8703 rad/s^2) were in the next ranks, respectively. Comparing these accelerations with the threshold of TBI, hook kick in boxing and spin kick in taekwondo can lead to concussion (4500 rad/s^2) (11) and DAI and ASDH injuries (10000 rad/s^2) (12) but in the impact of Hook kicks, straight punches and roundhouse kicks in taekwondo, the athlete only exposes to concussions.

In the MMA field, the highest rotational acceleration produced in head was due to the roundhouse kick (7069.5 rad/s^2), which leads to concussion compared to the head injury threshold.

In Judo, the highest rotational acceleration of head was caused by an Osoto-gari impact (4572.6 rad/s^2), which is a bit higher than the concussion threshold, and in wrestling, the head impact caused by the landing resulting from grappling as well, with a 1698/8 rad/s^{2}rotational acceleration, that was lower than the threshold of TBI.

According to the results, it can be said that boxing, taekwondo and MMA are exposed to more TBI among combat sports; and the most dangerous kicks in combat sports are hook, rotating kick, hook kick, direct punch and roundhouse kick. Also, the kicks in taekwondo can produce rotational acceleration more than the other field sport.

Headgear

Headgears are mostly used in boxing, taekwondo and MMA sports. In this study, in few cases, the use of headgears in boxing has shown low rotational acceleration of TBI (4500 rad/s^2). In most cases, this value has been higher than 4500 rad/s^2. Also, in three studies, in condition of not using a headgear, the rotational acceleration produced in head was less than head injury threshold in direct and uppercut punches. Therefore, it can be acknowledged that the use of headgears in boxing may increase rotational acceleration and increase the risk of TBI. In 2013, the International Association of Amateur Boxing announced that not using a protective headgear in boxing reduces the risk of injury by 43% (13). This can be due to the fact that by using a headgear, more areas of head are exposed to hit, on the other hand, due to the limitation of vision, the puncher may inflict dangerous blows on the opponent. Moreover, if boxers use a headgear, they think that their heads are protected, and for this reason, they do not pay much attention to the blows that are inflicted. But with the removal of the hedger, boxers have to change their tactics so that with better defense, the least blow to head will be inflicted. So, this association banned the use of headgear in all competitions. However, this does not seem to be an effective measure to reduce injuries, although it has been able to reduce brain injuries, but due to the aggressive nature of boxing, it has caused an increase in facial injuries and bruises (14, 15). Therefore, it is necessary to design headgear with the property of reducing rotational acceleration, as it has done in sports such as American football and rugby (16, 17).

After all, special research in evaluating the impact of protective equipment on rotational acceleration is necessary.

In Taekwondo, despite the use of headgears, the amount of rotational acceleration above the head injury threshold (4500 rad/s^2) has been reported. Only one study was found the rotational acceleration on head (4455 rad/s^2) despite the use of a headgear. In the rest of the studies, the acceleration amount was higher than this figure and in some, it reached higher than (10000 rad/s^2). This shows that taekwondo athletes are more exposed to severe TBI. Therefore, in order to increase the safety of taekwondo athletes, it is necessary to design headgears with the ability to absorb more shocks with the aim of reducing rotational acceleration. Also, for the safety of the athletes, it is suggested to revise the refereeing rules in this sport. For example, in Judo, throws that have a high risk of injury (Kani-bassami, Kavaz and Gik) are currently prohibited (18).

Headgears are not usually used in grappling sports (judo, wrestling) and also in MMA (19, 20). In Judo, due to the lack of headgears to reduce the risk of TBI, more emphasis is placed on the use of low-risk techniques with correct movement patterns (21).

Amateur wrestlers are also required to wear headgear in some countries. However, these headgears are mostly used for ear protection and have no known protection against TBI injuries (19). In this study, for the sport of MMA, headgears were exclusively used in two cases. Although wearing a headgear showed a lower rotational acceleration than not using it, these values are not lower than the head injury threshold. As you can

see in the results of this survey, despite the use of headgears in boxing, Taekwondo and MMA, in many studies the rotational acceleration has been reported to be higher than the threshold of TBI (4500 rad/s^2) (11), which is a debatable and challenging issue. It is suggested that more researches be done in the field of protective headgears in combat sports.

Preventive measures in TBI injury

One of the ways to reduce TBI injuries is probably the timely identification of injured athletes and their removal from the competition and timely evaluation by a physician. Another way to reduce damage is probably to use correct attack and defense movements. For example, in Judo, athletes should be taught to break fall (Yokomi technic) when landing to minimize the risk of TBI. This technique is known as the art of falling in such a way that when the athletes are exposed to a powerful attack by the opponents, they consciously throw themselves to the ground to avoid injury. In this type of conscious throwing, the damage is less than when the athletes are under the opponent's attack fall to the ground unconsciously. In Yokomi, when a person falls to the ground, he leaves his body in such a way that his head does not have direct contact with the mat. So, TBI can be reduced (22). Also, if in Taekwondo, instead of using high-risk kicks such as rotation kicks, simpler kicks are used, the damage of TBI will be probably reduced. Similarly, in boxing, the punches can be used which leads to less rotational movement in the head, then the rotational acceleration will be reduced.

Clinical recommendations and future work

The difference between the methods along with the specific test conditions in each study affects the results obtained in different researches. In the laboratory environment, such as the use of athletes and human dummies, this includes athletes who hit the dummies with different forces, but in the method of using mechanical dummies, the lever of the impacts, which represents the kicks and punches of the athlete, hits these dummies with constant speeds. In human studies, there are physical variables that cannot be included in other studies. The use of human methods can also expose athletes to serious risks, so the use of these methods is contrary to ethical standards. Although in using mechanical dummies, the subject will not expose to the risk of hit, it does not still reflect the actual conditions of the competition. Hence, it is suggested that in order to achieve more accurate results and close to the reality, a study on the methods of assessing head injuries in combat sports has been conducted in order to determine the best assessment method.

Researches have shown that due to the lack of knowledge of coaches and athletes about TBI, its symptoms and also the flow up measurements, 40% of athletes immediately return to the competition, while the risk of TBI is still existed. Therefore, clinical training of trainers, officials and athletes is necessary and must be included in the training programs of federations.

Another clinical recommendation is to evaluate the rotational acceleration of athletes' techniques and provide a suitable training program and sufficient rest time between sessions to reduce rotational acceleration. It is also recommended that first of all athletes be trained for the low-acceleration skills technics, then trained with the high necessary acceleration skills gradually. .

Overtraining and fatigue is another factor that can hit dangerous areas of the head and lead to serious injuries due to lack of proper technique and necessary concentration of blows, so it is recommended to pay special attention to these important factors in the training program. Also, the cumulative effect of sub-injurious blows in combat sports should not be forgotten. There is evidence showing the effects of repeated blows to the head leading to dementia, depression and chronic traumatic encephalopathy (CTE) (23).

Musculoskeletal injury is also more likely following TBI in sports (24) and neuromuscular risk factors should be considered while determining return to competition. Improper management of these effects increases the short-term risk of severe TBI, which should be carefully considered.

Limitations

In the reviewed studies, there were few ones that specified the type of rotational acceleration (average or peak). Awareness of this issue could provide more accurate information on TBIs.

In this review, the effects of other biomechanical variables such as speed and impact time were not considered. Also, the demographic characteristics of the athletes (age, gender, height, weight, experience level) were not taken into account which is also likely to affect the results of the research.

Conclusion

Impacts to the head in martial arts cause significant rotational acceleration. On the other hand, blows that hit the head directly, such as punches, create higher rotational acceleration than blows caused by throwing, so it seems that athletes in Boxing, Taekwondo, and MMA are at greater risk of TBIs. Protective headgear in combat sports cannot significantly reduce rotation speed, and this issue can even increase rotation acceleration in some sports such as Boxing. Therefore, it is suggested that those in charge of this matter and headgear manufacturing companies pay special attention to this matter and take an important step in reducing TBI injuries by re-examining the design of headgears.

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