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COMPARISON OF THE INCIDENCE AND CAUSES OF INJURIES IN STAND-UP AND GROUND COMBAT-SPORT FIGHTERS – A NARRATIVE REVIEW

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Abstract
Injuries in combat sports can happen to any athlete, regardless of gender, age, training experience or whether he or she is an amateur or a professional. The range of injuries varies from superficial, short-term damage to severe injuries with serious consequences, including death. There are many types of combat sports, each with different rules and specific injuries. Amongst various divisions of combat sports, one of the basic ones is the division into ground and stand-up sports. In the following work, using the available literature, we wanted to present the specifications of several of the most popular combat sports and compare their most common locations of injuries, types of injuries and mechanisms of their formation, paying attention to which of these categories a given sport belongs to. We also discuss differences in the rate of injury for different age, genders, prevalence of injuries during situations of practice and competition. In the end, it is presented what are the possible long-term complications of injuries in combat sports and which actions such as protective gear, bans on certain techniques or behavioural changes might reduce the injury rate to protect the athletes health, well-being and decrease the economic burden on healthcare systems.

Keywords
combat sports, sport injuries, boxing, kickboxing, Brazilian jiu-jitsu, taekwondo, judo, karate, judo, wrestling

Introduction

Fighting sports, also known as combat sports, involve one-to-one combat between competitors. This is a very diverse group, significantly different in terms of rules, permitted and forbidden actions, obligatory equipment or even the athlete's primary position. Striking or stand-up combat sports are generally based on hits and kicks using hands, legs or head in order to strike the opponent while keeping a distance. This group includes disciplines such as karate, taekwondo, boxing, kickboxing or muay thai. On the other hand, grappling sports, also known as ground-fighting sports and including judo, Brazilian Jiu-Jitsu (BJJ) and wrestling, are rather close-quarter, with throws, holds, submissions and other actions aimed to win the match [1].

Regardless of the fact that due to their nature, combat sports can be very traumatic and result in various injuries, these disciplines gain more and more popularity. Some estimates claim that 100 million people throughout the world practice different forms of martial arts. However, the group is very heterogeneous and research trying to investigate combat sports as a whole meet several obstacles [2]. As there are many amateur participants, various alternative styles and derivative martial arts, it seems almost impossible to calculate worldwide involvement in certain disciplines, especially when sports participation estimation methods vary in different countries. There is very little good-quality research diving into individual popularity rates for various fighting sports, with one outstanding report published by the Central Statistical Office of Poland in 2022. According to national counts, martial arts were one of the most popular sports overall, with a 13% participation rate. Most common combat sport disciplines in Poland were: karate (57 619 participants), judo (34 789 participants), Taekwondo (overall 17 523 participants for ITF and Olympic taekwondo), kickboxing (11 064 participants), boxing (11 047 participants), wrestling (7816 participants for both Greco-Roman and freestyle wrestling) and ju-jitsu (7 866 participants) [3].

Combat sports are even featured in the Olympic Games, and some of them have over 100 years of history in this competition. Wrestling (now with its two disciplines: Greco-Roman wrestling and freestyle wrestling) was featured in the first modern Olympic Games in 1896. Boxing had its debut at the Olympics in 1904, judo in 1964 and taekwondo in 1988. Karate was included in the 2020 Olympic Games program, but it will not appear this

year in Paris [4]. A sporting event of an unusual scale that is the Olympics makes a great opportunity to investigate how hazardous certain disciplines are for trained professionals. During the 2020 Olympic Games in Tokio out of 5 sports with the highest incidence of injury, 2 were combat sports (respectively boxing with the highest recorded incidence of injury of 27.1 injuries per 100 athletes and karate with the 5th highest incidence of injury of 18.5 injuries per 100 athletes) [5]. It was calculated that during three consecutive Olympic Games, combat sports resulted in approximately 1 injury per every 24 exposures or 40.9 competition injuries per 1000 exposures [6].

This provokes further questions - what are the typical injuries in combat sports, do they affect similar locations or what impact has a fighting sport style on the type and incidence of injuries? To answer these questions, we conducted a literature search on combat sports with the division for stand-up and ground sports, with particular regard to the disciplines that were cited as the most popular in Poland in recent years.

Materials and methods

We conducted a literature search of Medline (PubMed), aiming to identify relevant studies published up to July 2024, discussing the topic of combat sports injuries. Additional searches included Google Scholar and backward search, analysing the references of the included papers. Appropriate keywords such as “combat sports”, “fighting sports”, “martial arts”, “karate”, “judo”, “taekwondo”, “kickboxing”, “boxing”, “wrestling” and “Brazilian jiu-jitsu” were used and combined with “injuries”, “injury incidence rate”, and “risk of injury”.

All citations were imported into the citation manager Zotero. We examined titles, abstracts, study population details including age, gender or level of professionalism, study methodology (with preference for prospective cohort studies, cross-sectional studies, epidemiological studies etc.) and results, in order to gather information on types, locations and prevalence of injuries in 7 most common combat sport disciplines.

Results

The following review presents the most common injuries from four stand-up combat sports (boxing, kickboxing, karate, taekwondo) and three ground combat sports (judo, Brazilian jiu-jitsu, wrestling). The numbers of injuries described in the articles ranged from 80 [7] to 580 [8] in the case of stand-up sports and from 24 [9] to 1052 [10] in ground sports. In most works, men were the dominant group. Only in the article by Kim et al. the number of men and women was the same [11]. In one work about BJJ and two works about wrestling there was no differentiation on male and female athletes [12, 13, 14]. Age range of an athlete for each sport is presented in Table 1. Reviewed literature greatly differed in population mean age, as some described children and adolescents, most focused on young adults, but there were also athletes in their 40s and 50s. Remarkably, both minimal and maximal ages were recorded in papers regarding karate injuries.

Table 1. Age range of athletes in reviewed works.

Sport	Boxing	Kickboxing	Judo	Brazilian jiu jitsu	Karate	Taekwondo	Wrestling
Age range	18-43 [15-19]	15-48 [20, 21]	10-35 [9, 11, 22, 23]	15-39,6 [10, 12]	6-53 [24-26]	10-36 [7, 8, 27, 28]	9-34 [13,14, 29]

Different authors tend to focus on varied populations in terms of the level of the professionalism of the athletes. In the reviewed boxing publications, all the people were professionals [15-19]. The same is true for judo [9,11,22,23]. In the case of kickboxers, one work included only professionals [20], while the other included respectively 435 professionals and 59 amateurs [21]. Likewise were the papers describing injuries in Brazilian jiu-jitsu, where in one of the works there are only professionals [12], while in the second one 63.9% of the study participants took part in at least one competition per year, on regional, national or international level [10]. For the articles describing karate, in one work there were only professional athletes [25], the second one divided athletes into subgroups based on the colour of the belt [24], and another one recruited members of karate clubs without specification on their professionalism level [26]. Amongst the reviewed taekwondo articles, one described professional athletes [28], other work featured a group of amateur athletes [27]. The remaining two

works contain both professionals and amateur participants [7,8]. Publications about wrestling described only professional athletes.[13,14,29].

Injury locations are often linked to the specificity of a certain discipline, including technique differences or competition rules. The tables below present publications regarding each of the described sports, specifying 3 most popular locations of injuries and the most common types of injuries.

Table 2. Injury location and type in standing sports (boxing, kickboxing, karate, taekwondo)

Boxing		
Article	Injury region (n; % of all)	Type of injury (n; % of all)
Zazryn et al. 2003[15]	Eye, eyelid, eyebrow (49; 45.8%) Concussion (17; 15.9%) Face (16; 15.0%)	Open wound/laceration (71; 66.4%) Concussion (17; 15.9%) Superficial (includes bruising, blisters, and inflammation: 8; 7.5%)
Loosemore et al. [16]	Hand (69; 23%) Wrist (31; 10%) Elbow (23; 7.7%)	Not described
Zazryn et al. 2009[18]	Eye (64; 29.9%) Eyebrow (38; 17.8%) Concussion (25; 11.7%)	Open Wound/ Laceration/Cut (137; 64%) Concussion (25; 11.7%) Fracture (18, 8.4%)
Bledsoe et al. [19]	Face (99; 51%) Hand (33; 17.4%) Eye (28; 14.4%)	Not described
Kickboxing		
Article	Injury region (n; % of all)	Type of injury (n; % of all)
Dantas et al. [20]	Thigh/Knee/Shank (46; 35.7%) Ankle/Foot (18; 13.95%) Wrist/Hand (18; 13.95%)	Contusion (34; 26.4%) Sprain (25; 19.4%) Excoriation (20; 15.5%)
Lystad [21] - *results signed as location unspecified and injury unspecified were not included*	Head (115; 30%) Lower leg (17; 4.5%) Knee (15; 4%)	Laceration (96; 25%) Fractures (28; 6.6%) Organ injury (4; 1%)
Karate		
Article	Injury region (n; % of all)	Type of injury (n; % of all)
Čierna et al. [25]	Face (179, 69.6%) Upper extremities (21, 8%) Trunk (26, 10%)	contusions (100, 38.9%) abrasions (63, 24.5%) epistaxis (62, 24.1%)
Destombe et al.	Lower limbs (29, 35%)	Hematomas (43, 52%)

[24]	Upper limbs (24, 28.9%) Head (22, 26.5%)	Sprains (16, 19%) Muscle lesions (7, 7%)
Ziaee et al. [26]	Head and neck area (61%), Trunk (24%) Lower limb (12%)	Contusion, redness, bruise, superficial scratch (80, 64%) Superficial wound, deep wound, bleeding (31, 24.8%) Luxation, tendon stretching, fracture (14, 11.2%)
Taekwondo		
Article	Injury region (n; % of all)	Type of injury (n; % of all)
Ji [8]	Foot (93, 16%) Knee (86, 14.8%) Ankle (80, 13.8%)	Contusion (319, 48.4%) Strain (89, 13.5%) Sprain (75, 11.4%)
Lystad et al.[27] - *Injuries during training and competitions were counted together. Unspecified location and other/undefined type of injury were not counted.*	Wrist & hand (23, 13.3%) Ankle (23, 13.3%) Foot (23, 13.3%)	Muscle strain (33, 19%) Contusion (30, 17.3%) Joint sprain (24, 13.9%)
Son et al. [28]	Foot (72, 21.43%) Ankle (70, 20.83%) Knee (51, 15.18%)	Ligament sprain (92, 27.38%) Contusion (83, 24.70%) Fracture/stress fracture (71, 21.13%)
Covarrubias et al. [7]	Foot (39, 30.00%) Ankle (15, 11.54%) Knee (14, 10.77%)	Contusion (48, 41.74%) Sprain (26, 22.61%) Strain (16, 13.91%)

The dominant regions in papers describing boxing injuries were: face, especially eye area, upper extremity (hand and elbow). There were also several concussions. Kickboxing traumas often affected lower extremity (thigh, knee, shank, ankle and foot). For karatekas, many reported injuries occurred in the face, head or neck, both lower and upper extremity regions, as well as the trunk. Literature describing taekwondo traumas mainly points out many lower extremity injuries, including these specific to the foot, knee and ankle. By contrast, in one study the most common location was wrist and hand.

Table 3. Injury location and type in ground-based sports (judo, Brazilian Jiu-Jitsu, wrestling)

Judo		
Article	Injury region (n; % of all)	Type of injury (n; % of all)
Cierna et al. [9]	Nose (5; 20.8%) Head (4; 16.7%) Wrist and hand (4; 16.7%)	Contusion (8; 33%) Dislocation (4; 17%) Laceration (4; 17%)
Kim et al. [22]	Lumbar spine/lower back (85; 10.9%) Shoulder/clavicle (80; 10.2%) Knee (76; 9.7%)	Not described
Błach et al. [23]	Knee (121; 17.4%)	Sprain (293; 42.2%)

	Shoulder (109; 15.7%) Elbow (99; 14.2%)	Contusion (160; 23.1%) Luxation (61; 8.8%)
Kim and Park [11]	Knee (114; 18.5%) Shoulder (102; 16.5%) Lumbosacral (72; 11.7%)	Strain (179; 29%) Joint sprain (162; 26.3%) Tendinosis (57; 9.2%)
Brazilian Jiu-Jitsu		
Article	Injury region (n; % of all)	Type of injury (n; % of all)
Scoggin et al. [12]	Elbow (14; 30%) Knee (7; 15%) Foot and ankle (5; 10.9%)	Ligament sprain (22; 47.8%) Tenderness (3; 6.5%) Joint dislocation (3; 6.5%)
Hinz et al. [10]	Knee (84; 8%) Rib (84; 8%) Shoulder (71; 6.7%)	Rib Injury (Bruise, Contusion, Fracture) (80; 7.6%) Meniscal Injury (57; 5.4%) Ligamentous Ankle Injury (44; 4.2%)
Wrestling		
Article	Injury region (n; % of all)	Type of injury (n; % of all)
Pasque et al. [29]	Shoulder (52, 24%) Knee (38, 17%) Hand/Wrist (25, 11%)	Muscle strain (67, 30.6%) Joint sprain (50, 22.8%) Bruise (35, 16.0%)
Otero et al. [13]	Skin (181, 17.5%) Knee (177, 17.1%) Head and face (173, 16.7%)	Not described
Agarwal et al. [14]	Knee (71, 37.77%) Shoulder (35, 18.62%) Spine (21, 11.17%)	Only types of knee injury were described: Strains (14, 18.18%) Prepatellar bursitis (13, 16.88%) Bone Contusion (9, 11.68%) Effusion (9, 11.68%)

In judo, the common location of injury was shoulder and clavicle, as well as lumbar region and knee. Only in one paper the most common regions were the head region and hand, including wrist. For Brazilian Jiu-Jitsu, most injuries affected extremities: lower (knee, foot, ancle), and upper (elbow, knee). In wrestling articles, attention is drawn to the prevalence of injuries to the knee and shoulder. Other common locations (hand, wrist, head, face, spine) were individual for each research.

Discussion

Frequency of injuries

The fact that combat sports are traumatic is undeniable. While reviewing the articles, we tried to choose the most injury-prone sport. However, the above articles used different units to quantify the number of injuries suffered by athletes. In articles describing boxing injuries, authors used for example injuries or injured boxers per fight participations or per boxing rounds. In this case the frequency was respectively 250.6 injuries per 1000 fight participations and 220.1 injured boxers per 1000 fight participations [15]. The same author in his other work described injury rate 23.6 per 100 professional fights [18]. Blesode et al. used a similar way, describing 17.1 injury per 100 boxer-matches or 3.4 per 100 boxer-rounds.[19] Another author described frequency of injury as injuries per hour of competition time. This rate was 828 per 1000 h of competition time and hand injury time amounting to 302 per 1000 h [16]. In karate publications, authors wanted to describe the frequency of injuries

per athlete. The results were 44.6 injuries per 100 athletes [24] and 20.2 injuries per 100 athletes.[26] Another author described 41.4 injuries per 1000 athlete exposures [25]. In kickboxing Lystad also used injury per athlete exposure, finding the rate of 390.1 injuries per 1000 athlete exposures and also time related rate of 39.7 injuries per 1000 minutes of exposure [21]. Another author stated that there was a median of 3 ± 3 injuries per athlete.[20] In the last discussed standing sport, taekwondo, one of the authors used a time related rate with the following results: 1.6 injury per athlete-year, 11.8 injury per 1000 athlete-training-sessions, and 7.0 injury per 1000 athlete-hours of training [27]. Another author used a common unit of injury per athlete exposure with a result of 6.31 injury per 1000 athletes-exposure [28]. The other two authors did not describe the rate of injury [7,8].

In articles regarding ground combat sports, authors used similar rates as in stand-up sports. In Brazilian Jiu-Jitsu authors calculated injury rates as incidence per exposure or the numbers of injury in the study group. The results were: 9.2 injury incidence on the day of matches per 1000 exposures [12] and 784 injuries per 1140 athletes [10]. In works about judo, one of the authors used the injury rate per athlete or per minutes of exposure. Results were: 8.1 injuries per 100 athletes or 35.6 injury per 1000 athlete-exposure. In the time rate, it was 10.9 injuries per 1000 minutes of exposure [9]. Other authors used a similar rate, describing 4.2 injuries per 1000 hours of training per athlete [22] and 12.60 injuries per 1000 athletes exposures [11]. In wrestling works, all authors used injury per athlete exposure as a rate. The results were as follows: 5.13 injuries per 1,000 athlete exposure [14], 6.0 injuries per 1000 athlete exposures [29], 19.6 injuries per 1000 athlete exposures [13]. Additionally, one of the authors used a time-related unit, describing 52 injuries per 100 wrestlers per season [29].

Looking at the above data, we can see that the most popular rate, used in every sport except boxing and Brazilian Jiu-Jitsu, was injury per athlete-exposure. This rate shows that amongst described sports, the one that causes the most injuries is kickboxing.

Common types of injuries and their mechanisms

Standing combat sports

The presented statistics show that among stand-up sports, the predominant location is the head and face area, then the lower limbs, ending with the upper limbs. When it comes to types of injuries, superficial injuries such as contusions, bruises, abrasions and lacerations dominate. Next are various joint injuries such as sprains, dislocations, ligament damage and muscle strains. Other injuries, such as fractures, concussions, and bleeding, occurred less frequently and in specific sports.

In boxing, where, unlike other sports, the use of legs is prohibited [15], the characteristics of injuries are different. There are no injuries to the lower limbs, but there are more head injuries, including concussions or eye injuries including retinal detachment [16]. Also occur injuries to the upper limbs, with particular prevalence of injuries of hands and wrists. The location of injuries is mainly due to what regions boxers focus on while striking their opponent. Blows directed mainly to the head, neck and torso increase a risk of different injuries. “Cauliflower” ears, hearing impairment, nose injuries, cardiac and pericardial injuries and acute renal injuries have been also reported in the literature [19]. In case of long-term injuries, it has been noted that boxers who were more likely to receive blows to the head and were more prone to be defeated by knockout or technical knockout, have had an increased likelihood of brain lesions in computed tomography and neurological complications such as boxing dementia, especially if they were from a susceptible population [19]. Fight mechanics play an important role in upper limb injuries in boxers. Punches delivered by boxers can generate enormous force, comparable to being hit with a hammer at high speed [19]. Such force also exposes the attacker to injuries, mainly to the hands and wrists, if they are not well protected.

In other sports, the number of head injuries is reduced in favour of lower limb injuries, which is due to their permitted use. Dantas et al. pointed out that kickboxers are exposed to heavy physical stress because of lots of various actions that they have to perform during the fight. He also draws attention to the fact that the most common cause of leg injuries were direct kicks, and injuries to the abdomen and lower back were also caused by the need to stabilize the torso during the kick [20].

The given frequency of injuries in the case of karate may be dictated by the scoring that occurs in this sport. Kicks, especially those to the head, are scored better than punches [30]. Čierna et al. explain that a higher number of head and face injuries in karate can be prevalent in a group of top-level athletes, because they perform more actions to the head than to the torso [25]. Destombe et al. cites blocking attacks, kicks and lack of proper warm-up as the mechanisms of injury [24].

The same mechanisms are described by Son in work about taekwondo [28]. Ji explains the highest frequency of lower limb injuries as a result of the fact that the athletes often perform kicks at the same time. Additionally, similar to the observation that karatekas who use more kicking are more susceptible to injury [8], Lystad et al. speculated that the difference between injuries during taekwondo training and competition result from the fact that in training fighters do not use strong high kicks [27].

Ground-based combat sports

The presented statistics show that the most common injuries in ground sports are injuries to joints such as the knee, shoulder, wrist or ankle. Next, we see head and spine injuries. Common types of injuries include major dislocations, sprains and ligament injuries. Frequent damage to knee components had also been reported. Other injuries include bruises, contusions, fractures and muscle strains.

In Brazilian Jiu-Jitsu, Hinz et al. lists submissions, takedowns, and guard passes as the main reason for injury. The armbar, the kimura, and the heel hook were submission techniques that caused the most injuries. There was only one injury caused by the choke technique [10]. Scoggin et al. explain that armbar injuries were caused by hyperextension to the elbow when the athlete tried to resist the arm bar and did not give up quickly enough. In Brazilian Jiu-Jitsu punches, strikes, or kicks of any kind are not allowed, which explains the lower risk of lacerations and concussions [12].

As the main reason for injury in judo Stephenson and Rossheim described being struck and landing [31]. Lystad et al. noticed that judo, which does not allow any striking, is the lowest injury sport from full-contact combat sports [32].

As the main injury situation in wrestling Pasque et al. described the moment when athletes try to take each other down to the mat. It is likely attributable to the high intensity, speed, and forces involved when trying to take the opponent to the mat. More traumatic position was the defensive position. Direct forces, blows and twisting forces was the main mechanism of injuries [29]. Agarwal et al. described knee injuries as the most common injuries in wrestling, adding that they are usually injuries that require surgery and end the athlete's season. They also found that more knee injuries occurred in the attack position which may be the result of lack of appropriate skills. Remarkably, this work also indicates one disease entity that occurs almost exclusively in this sport, i.e prepatellar bursitis [14].

Sex-specific differences in injury patterns

As mentioned above, most reviewed literature had a great male participants domination. Some research searched for significant differences in injury incidence rate in male and female athletes. To begin with standing combat sports, men were more likely than women to be injured in boxing [18, 19] and kickboxing [20, 21]. Bledsoe et al. wonder whether the difference in boxing might be due to the fact that female boxers fight fewer rounds per match (women's boxing matches are usually maximum 10 rounds, with 2 minutes per round, while men's boxing matches are 12 rounds of 3 minutes each) or that probably due to increased punching power of heavier male athletes, knockout rate for men is 5 times higher than for women [19].

In two out of three karate papers the incidence of injuries was similar or there were no significant differences between male and female karatekas [24, 25]. One research found lower injury rates in women with a rate ratio of 0,63 [25].

Two articles about taekwondo found no significant differences between injury frequency in males and females [7, 27], one didn’t calculate this parameter at all [8]. Nevertheless, one paper found higher injury incidence rates in women than in men: female athletes were 1.49 times more likely to sustain an injury while practicing or taking part in Taekwondo competitions. Yet these authors did not observe any significant differences in the location, type nor mechanism of the injury between male and female athletes [28].

By contrast to boxing or kickboxing, two reviewed articles regarding judo injuries proved that female judokas have higher injury frequency than male athletes [22, 23], which comes as a surprise in comparison to other combat sports. One judo study found that heavyweight women experienced significantly more injuries classified as grade III (requiring more than 8 days of treatment) than heavyweight men. They also had a higher annual injury rate [22]. Another article found differences in injury location in judo - women had statistically significant more elbow injuries. However it was men who had experienced more bleeding episodes [23]. Kim and Park

suggested that a higher injury rate of female judokas might be due to the "lack of neuromuscular component", that would result in inadequate joint stability and protection. Regardless of the above information, in Kim et al. the difference in the injury rate between sexes was not statistically significant [11].

It is not possible to draw conclusions on that topic from reviewed wrestling as in Pasque et al. there were only male participants and two other works didn't differentiate injury rates between genders [13,14,29].

Searching for a link between injuries and age

Generally speaking, martial arts are sports of the young, as many people start practicing as children or adolescents and this type of sport is becoming increasingly popular in these groups. For example, in certain regions of the USA the enrolment of children in some martial arts has more than doubled in recent years [22, 25]. Consequently, it seems reasonable to study the relationship between age and injury incidence to determine whether young practitioners are protected by factors such as their elastic tissues or more prone to injuries for instance because of the poorer technique.

In one of the BJJ study, older age was named a significant risk factor for sustaining an injury in the 3-year time period [10], and in the second reviewed work incidence of injury was 4.1 per 1000 exposures in competitors aged less than 15 years old and as high as 10.8 per 1000 exposures in the older group (more than 16 years old) [12].

Also older boxers were more likely to be injured, but the research is inconsistent in pointing out the most affected group. Zazryn et al. in the 2009 work noticed an interesting trend that the injury risk was increased for Australian boxers between 18 and 23 years old, then the level would reach a plateau until 28 years old with again apparent increased risk about 35 years of age [18]. By contrast, a British study by Loosemore et al. found quite the opposite, as that the highest injury incidence rate was true for boxers at the 25-36 years old age group [16].

In articles concerning karate, two papers found that athletes with injuries were older [24, 25]. Cierna et al. additionally suggests it might be due to the fact that World Karate Federation rules in the under 18-year-old category limit face contact to a greater extent than in the under 21-year-old competition category. Opposed to these findings is the Iranian study that examined only athletes younger than 30 and where the most injuries were noted at the age of 18 [26].

Only one of the reviewed taekwondo papers provides information on the impact of age. Interestingly, incidence rates were higher for adults than in youth athletes for practice-associated injuries, but for injuries that occurred during competition the opposite was true (youth competitors were 2.00 times more prone to injury than adult fighters). Adult taekwondo athletes were also 2.82 times more likely to experience a severe injury than young ones [28].

Finally, in the high school wrestler's population it was found that injured wrestlers were an average of 5 months older than the uninjured ones [29]. Agarwal et al.'s study that focuses on knee injuries points out a statistically significant association between knee injuries and age, with 60.56% knee injuries in the age group of 20-24 years [14].

In the rest of the reviewed articles the authors did not find any significant association between age and the incidence of injury [7,13,20,21,27] or the presence of such a link was not discussed in the paper [8,9,11,15,16,22,23]. Surprisingly, none of the reviewed judo works mentioned any results of the analysis of the age and injury rate association. Yet it must be pointed out that some of the papers had a narrow age range as shown above in Table 1, which might have impeded statistical analysis on that matter. Therefore, it should be regarded with caution whether the trend of the injury risk increasing with age could be true for combat sports in general.

Comparison of injury rates during training to injury rates during competition

In the articles we described, injuries occurred during various activities and, depending on the sport, their frequency differed between them. In boxing more injuries occurred during training than competition. In both cases, hand injury was the most popular location [16]. Kickboxing papers noticed a huge predominance of injuries during training, which was 92.6% to 1.85% of injuries during competition [20]. Similar results were obtained in articles on karate, where proportion of injuries during training to competition was 33.9/100 to

10.7/100 [24]. Another author described in his work 90% injuries during training, 4% during competition and 6% as a result of bad warm-up [26]. Covarrubias et al. reported more injuries during practice than during competition, explaining this linked with more time spent training than competing [7]. Lystad et al. obtained similar results in his work, additionally pointing out the lack of difference between training injury and competition injury in localization and type [27]. Son et al. reached different results. In his work there were more injuries during competition and there was a difference in type of injury and body localization [28]. In articles about Brazilian Jiu-Jitsu Petirson et al. showed the predominance of injuries occurring during competition and difference in injury main localization [33]. On the other hand, Hinz et al. indicated sparing as the main reason for injury. Injuries during competition were less than 10% [10]. Pasque et al. in the work about wrestling described more injuries in practice than during competition. Among injuries during training, the most common were these during sparring [29].

What can be done to reduce injury rates and complications?

As it was discussed, martial arts are hazardous sports with rather high risk of different injuries. To protect the participants, rules and regulations have been implemented. Athletes might be obliged to wear specific equipment, for example boxers must wear gloves with a certain thickness, a mouthguard and a groin guard [1]. Karatekas at the Olympic Games are required to wear protective gear approved by the World Karate Federation, that is: mitts, body protector, shin pads, foot protection and a gum shield. Female karatekas must also wear a chest protector [25]. On the other hand, in kickboxing rule sets and requirements for protective equipment greatly vary in different contests. Most competitions require hand-wraps, 10-ounce (283 g) boxing gloves, groin guards, mouth guards and shin pads. Amateur athletes and adolescents under 16-year-olds are often obliged to also use padded kick-boots and additional head gear [21]. Nevertheless, not all protective equipment has only a positive impact. Face masks used in karate were frequently damaged, which caused face lacerations. In addition, it was suggested that a requirement for helmets in karate competitions could have led to more aggressive attacks to the head [1].

Besides protective equipment, there exist rules that ban certain actions. This is especially true for competitions of younger athletes, for example in karate under-18-year-old category it is prohibited to use excessive force in blows. If an athlete aims an attack to the forbidden area (throat, arms, legs, groin, joints, instep) or blows with open hand towards the face of the opponent, penalties might be enforced. Interestingly, in the category of under 21-year-old karatekas, light and controlled contact to the face, hand or sides of the neck is already allowed [25].

Additional actions might also decrease the risk of injury. Some athletes tend to reach for these means especially after being injured. For example, many injured BJJ fighters made behavioural adaptations such as stretching more, less intense fighting and earlier tapping (accepting the opponent's victory by a gesture) [10]. Undoubtedly it is important to have a well-established practice routine, but one of taekwondo works found that stretching, warming up and cooling down did not have an effect on the decrease in injuries [7]. Further research is yet needed to determine this matter.

Not only an acute issue - why injuries in combat sports might be a long-term problem?

Injuries acquired during practicing sports tend to be difficult to treat and can place an economic burden on the healthcare system [1]. An injury might also be a personal tragedy to a promising athlete as it might require taking some time off. In BJJ, competitors who took more than 4 months off after an injury were 5.5 times more likely to consider quitting their sport [33]. Some injuries defined as season-ending may thwart the plans of an ambitious contestant, since they can be very serious. For example, in wrestling such season-ending injuries were knee meniscus tears, anterior cruciate ligament tears, subluxations or dislocations of the shoulder or elbow [29]. Form of treatment is also important: injured BJJ fighters that needed to have surgery were 6.5 times more likely to consider quitting than those with no treatment or other forms of treatment [33].

Fatal injuries in combat sports are rare, but it is important to remember that each sport, especially as hazardous as fighting competitions, might have lethal complications. One of the deaths reported in the literature was an Australian beginning boxer who collapsed during the 6th round of the fight and suffered from a left frontoparietal subdural haemorrhage with cerebral infarction and associated oedema. Factors that were investigated in link with this fatal event included dehydration, issues of weight loss (crucial before a fight in boxing) or mismatching the victim with the opponent, yet eventually they were not claimed to have surely contributed to the death of the boxer [18]. Literature on karate also provides some examples of fatal events: it was reported that a 20-year-old male karateka received a roundhouse kick, fell on the unpadded floor and

suffered from an extradural hematoma that caused his death. There are also reports on strokes with hemiplegia after a strike to the neck near the carotid artery [24]. These stories seem to highlight the need to implement rules such as a prohibition on aiming to the neck in karate.

From the perspective of long-term consequences, head injuries are a particularly threatening type, because repeated head traumas are associated with decreased cognitive function and some brain structure degeneration [21]. For example, kickboxing was linked to chronic repetitive cranial traumas that could result in neurological abnormalities. To prevent the oversight of such cases, it was suggested to provide kickboxing athletes and coaches with a concussion education program [20]. Surely, it seems crucial to determine all factors that can help decrease the rate of these situations and protect combat sports athletes.

Limitations

The main problem when comparing injuries from different sports is defining what an injury is. Each sport has different injury reporting protocols, which also makes it difficult to compare them. There are also no special ICD9 codes for individual disciplines. The reporting rate of injuries is also unknown, as many traumas in the amateur sector are probably left undetected. Another issue is the fact that individual injuries have different effects on specific sports, for example a knee injury will not have such dire consequences for sports that do not involve kicking, so it might not be detected and linked with this sport in some epidemiological studies. In reviewed publications, authors described various groups of players, both amateurs and professionals. Among the amateurs, there was no information regarding their training experience, level of training or number of training units per week, as this information cannot be obtained in an objective way. It is also very difficult to determine recovery time among amateurs. Finally, we can only estimate how many people in the world practice specific sports, so it is impossible to determine the exact injury rate in specific sports.

Conclusions

Injuries are inherent in combat sports. With their close-contact, techniques such as striking, kicking, knocking-out or taking down the opponent, it seems impossible to fully avoid any injuries. In this review we described the link of injury location and type with fighting techniques specific to each sport. It was proven how stand-up and ground-based sports might have vastly different injury rates and mechanisms. Factors such as gender, age or whether more injuries occur in practice or in competition are highly specific to each described combat sports. There are many ways to reduce injury prevalence, amongst them are protective equipment, bans on certain moves and actions, as well as behavioural changes. It is very important for combat sports athletes to be educated on the type and location of injury that is the most common in their discipline, so that they can employ techniques to reduce the possibility of traumas where possible.

Author's contribution

For full transparency, all submitted manuscripts must include an Author Contribution Statement stating the work of each author. For research articles with multiple authors, a short paragraph must be provided stating their individual contributions.

The following statements should be used: Conceptualization, BG, and KM; methodology, AS; software, MK; check, PK, KK and MJ; formal analysis, KK; investigation, AS; resources, BG; data curation, KM; writing - rough preparation, BG, KM; writing - review and editing, AS, MK, PK, KK, MJ; visualization, AS; supervision, PK; project administration, KK; receiving funding, not applicable

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