Lystad, R. P., Alevras, A., Rudy, I., Soligard, T., Engebretsen, L. (2020). Injury
incidence, severity and profile in Olympic combat sports: a comparative
analysis of 7712 athlete exposures from three consecutive Olympic
Games. *British Journal of Sports Medicine, under utgivelse.*
https://doi.org/10.1136/bjsports-2020-102958

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https://doi.org/10.1136/bjsports-2020-102958

This is the final text version of the article, and it may contain minor differences
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https://doi.org/10.1136/bjsports-2020-102958

Injury incidence, severity, and profile in Olympic combat sports: a comparative analysis of 7,712 athlete exposures from three consecutive Olympic Games

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ABSTRACT

Objectives To describe and compare the epidemiology of competition injuries in unarmed combat sports (i.e., boxing, judo, taekwondo, and wrestling) in three consecutive Olympic Games.

Methods Prospective cohort study using injury data from the International Olympic Committee injury surveillance system and exposure data from official tournament records at three consecutive Olympic Games (i.e., Beijing 2008, London 2012, and Rio de Janeiro 2016). Competition injury incidence rates per 1,000 minutes of exposure (IIR_{ME}) were calculated with 95% confidence intervals using standard formulae for Poisson rates.

Results The overall IIR_{ME} was 7.8 (95%CI 7.0, 8.7). The IIR_{ME} in judo (9.6 [95%CI 7.8, 11.7]), boxing (9.2 [95%CI 7.6, 10.9]), and taekwondo (7.7 [95%CI 5.6, 10.5]) were significantly higher than in wrestling (4.8 [95%CI 3.6, 6.2]). The proportion of injuries resulting in >7 days absence from competition or training was higher in wrestling (39.6%), judo (35.9%), and taekwondo (32.5%) than in boxing (21.0%). There was no difference in injury risk by sex, weight category, or tournament round, but athletes that lost had significantly higher IIR_{ME} compared to their winning opponents (rate ratio 3.59 [95%CI 2.68, 4.79]).

Conclusion Olympic combat sport athletes sustained, on average, one injury every 2.1 hours of competition. The risk of injury was significantly higher in boxing, judo, and taekwondo than in wrestling. About 30% of injuries sustained during competition resulted in >7 days absence from competition or training. There is a need for identifying modifiable risk factors for injury in Olympic combat sports, which in turn can be targeted by injury prevention initiatives to reduce the burden of injury among combat sport athletes.

Keywords Athletic Injuries; Incidence; Combat Sport; Boxing; Judo; Taekwondo; Wrestling

What is already known?

- Combat sports have long-standing traditions in the Olympic Games.

- Current data suggest that the risk of injury in combat sports is high, although there is considerable variability in injury incidence rate estimates.

What are the new findings?

- Olympic combat sport athletes sustain, on average, one injury every 2.1 hours of competition.

- The risk of injury is significantly higher in boxing, judo, and taekwondo than in wrestling.

- About 30% of injuries sustained during competition result in >7 days absence from participation, with higher proportions in wrestling, judo, and taekwondo than in boxing.

INTRODUCTION

Combat sports have long-standing traditions at both ancient and modern Olympic Games. Wrestling has been contested at every modern Olympic Games since the inception in 1896, except for the Paris 1900 Olympic Games.[1,2] Similarly, boxing has been contested at every modern Olympic Games since its introduction in 1904, except for the Stockholm 1912 Olympic Games.[3] More recent additions are judo, which was first introduced in 1964 and has been contested at every Olympic Games since the Munich 1972 Olympic Games,[4] and taekwondo, which has been contested since the Sydney 2000 Olympic Games.[5] Lastly, karate will make its full Olympic debut at the Tokyo 2020 Olympic Games.[6]

Despite the popularity of Olympic combat sports worldwide, participation is not without risk and injury is a common adverse outcome.[7] Previous systematic reviews of injuries in Olympic combat sports have highlighted considerable variability in injury incidence rates across primary studies.[7-10] This variability has been attributed to methodological heterogeneity, including differences in operational injury definitions, exposure measures, surveillance methods, study populations, and other contextual factors (e.g., changes in competition rules over time). Unfortunately, this methodological heterogeneity has precluded meaningful comparisons of injury risks and profiles across combat sports.

To remedy this, it would be ideal to implement identical and ongoing injury surveillance systems across all combat sports; however, that would require access to considerable resources and substantial cooperation and coordination between combat sport governing bodies. An alternative and more realistic approach would be to leverage existing injury surveillance systems at multisport events. For instance, injury data from the International Olympic Committee (IOC) injury surveillance system,[11] can be combined with good quality exposure data from official tournament records to enable direct and meaningful comparisons of injury risks and profiles across Olympic combat sports, which in turn may inform decisions about participation and the need for protecting the health and safety of combat sport athletes.

The aim of this study was to describe and compare the epidemiology of competition injuries in boxing, judo, taekwondo, and wrestling using data from the IOC injury surveillance system and official tournament records at three consecutive Olympic Games (i.e., Beijing 2008, London 2012, and Rio de Janeiro 2016). Specifically, the objectives were: (1) to quantify and

compare competition injury incidence rates based on actual exposure time; (2) to quantify and describe the distribution of competition injuries by body location, type of injury, and injury severity; and (3) to identify potential risk factors for competition injury.

METHODS

Study design

Prospective cohort study.

Study population

Boxing, judo, taekwondo, and wrestling athletes competing at the Beijing 2008, London 2012, and Rio de Janeiro 2016 Olympic Games.

Data sources

Injury data were obtained from the IOC injury and illness surveillance system for multisport events from the Beijing 2008, London 2012, and Rio de Janeiro 2016 Olympic Games. The methodology for the IOC injury and illness surveillance system has been outlined previously.[11-14] In brief, all National Olympic Committee (NOC) medical teams were invited to report the daily occurrence (or non-occurrence) of injuries and illnesses using an electronic report form. Concurrently, information on all athletes treated for injuries in the polyclinic and all other medical venues operated by the medical staff of the Local Organizing Committee (LOC) at each Olympic Games were collected through an electronic medical record system. The following injury data were collected: accreditation number, name, sport and event, whether the injury occurred in competition or training, date and time, injured body part, type of injury, cause of injury, and estimated time lost from competition or training.

Exposure data were obtained from the official tournament records (i.e., draw sheets) that were compiled for each combat sport tournament at each Olympic Games. These draw sheets typically contain information about all individual contests, including name and nationality of competing athletes, weight division, tournament round, and outcome and duration of contest. The information on the draw sheets was cross-validated with information available from https://www.sports-reference.com/, a website that aggregates various sports statistics, and information available on the websites of the international sports governing body for each Olympic combat sport (i.e., the International Boxing Association, https://www.aiba.org/;

International Judo Federation, https://www.ijf.org/; World Taekwondo, http://www.worldtaekwondo.org/; and United World Wrestling, https://unitedworldwrestling.org/).

Operational injury definitions

Injury was defined as a new or recurring musculoskeletal complaint, concussion, or other medical condition incurred in competition during the Olympic Games receiving medical attention, regardless of the consequences with respect to absence from competition or training.[11-14] That is, re-injury after full recovery was recorded, whereas exacerbation of pre-existing injury before full recovery was not recorded. In cases where a single incident caused multiple injury types, only the most severe diagnosis was recorded. Estimated number of days absent from training or competition was used to determine injury severity. Injury severity was categorised using the following time bins: 0 days, 1-7 days, 8-28 days, >28 days, as recommended by the IOC consensus statement on methods for recording and reporting of epidemiological data on injury and illness in sport.[15] In regard to diagnoses, all recorded injuries were coded and categorised by body region and area as recommended by the IOC consensus statement on methods for recording and reporting of epidemiological data on injury and illness in sport.[15]

Data management and statistical analysis

For each combat sport, male and female weight divisions were dichotomised into 'light' and 'heavy' weight categories. If there was an even number of weight divisions, then the lighter and heavier halves of the weight divisions were designated as 'light' and 'heavy', respectively. If there was an odd number of weight divisions, then the lightest weight division was designated as 'light' and the lighter and heavier halves of the remaining weight divisions were designated as 'light' and 'heavy', respectively. See Supplementary Table 1 for a detailed overview of the dichotomised weight divisions for each combat sport, sex, and event.

Individual contests were dichotomised as 'preliminary' and 'final' tournament rounds. That is, preliminary tournament rounds comprised contests prior to quarterfinals (e.g., qualification rounds, rounds of 64, rounds of 32, and rounds of 16); while final tournament rounds comprised all subsequent contests (e.g., quarterfinals, semifinals, finals, and if applicable, repechage rounds and bronzefinals). Competition rules are revised from time to time, albeit major changes are relatively infrequent. The two most noteworthy rule changes that occurred

during the study period were the overhauling the scoring system in taekwondo after Beijing 2008 and the removal of protective headguards in men's boxing after London 2012. Thus, individual contests in taekwondo and men's boxing were dichotomized into pre- and post-major rule change accordingly.

Injury incidence rates per 100 registered athletes (IIR_{RA}), per 1,000 athlete-exposures (IIR_{AE}), and per 1,000 minutes of exposure (IIR_{ME}) were calculated with 95% confidence intervals (CI) using standard formulae for Poisson rates.[16] Combat sports and subgroups (e.g., female versus male, heavy weight divisions versus light weight divisions, final tournament rounds versus preliminary tournament rounds, losers versus winner, and post- versus pre-major rule changes) were univariately compared by computing the injury incidence rate ratio (RR), whereby two injury incidence rates were deemed statistically different from one another if the 95%CI for the RR did not include the null value (i.e., 1). All statistical analyses were conducted using the statistical software R, version 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria).

Ethical considerations

This research was approved by the Macquarie University Human Research Committee (reference number: 5201700320) and was conducted in accordance with the requirements of the National Health and Medical Research Council's National Statement on Ethical Conduct in Human Research (2007; updated May 2015).

RESULTS

Combat sport event at Beijing 2008, London 2012, and Rio de Janeiro 2016 Olympic Games comprised a total of 3,412 athlete registrations, 7,712 athlete exposures, and 40,250 minutes (670.8 hours) of exposure. Many athletes were registered at more than one event; hence, the number of unique athletes was 2,805. Of these, 750 (26.7%) were boxing athletes, 925 (33.0%) were judo athletes, 316 (11.3%) were taekwondo athletes, and 814 (29.0%) were wrestling athletes. They comprised 777 (27.3%) female and 2,028 (72.3%) male athletes.

Injury incidence

A total of 315 competition injuries were recorded among combat sport athletes during the three Olympic Games. The overall IIR_{AR}, IIR_{AE}, and IIR_{ME} were 9.2 (95%CI 8.2, 10.3), 40.9 (95%CI 36.5, 45.6), and 7.8 (95%CI 7.0, 8.7), respectively (Table 1). The highest IIR_{ME} were

observed in judo (9.6 [95%CI 7.8, 11.7]) and boxing (9.2 [95%CI 7.6, 10.9]), followed by taekwondo (7.7 [95%CI 5.6, 10.5]) and wrestling (4.8 [95%CI 3.6, 6.2]). Compared to wrestling, the IIR_{ME} was significantly higher in boxing (RR_{ME} 1.91 [95%CI 1.31, 2.62]), judo (RR_{ME} 2.00 [95%CI 1.44, 2.79]), and taekwondo (RR_{ME} 1.61 [95%CI 1.08, 2.41]). There was no significant difference in IIR_{ME} between judo and boxing (RR_{ME} 1.05 [95%CI 0.80, 1.37]). Although the IIR_{ME} in taekwondo was 19% and 16% lower than in judo (RR_{ME} 0.81 [95%CI 0.51, 1.16]) and boxing (RR_{ME} 0.84 [95%CI 0.60, 1.20]), respectively, the IIR_{ME} were not significantly different.

[insert Table 1 near here]

Injury severity

Of the 315 recorded injuries, 309 (98.1%) provided estimates of the number of days absent from training or competition. Of these, 155 (50.2%) were 0 days absence, 61 (19.7%) were 1-7 days absence, 53 (17.2%) were 8-28 days absence, and 40 (12.9%) were >28 days absence. The proportion of injuries resulting in >7 days absence was highest in wrestling (39.6%) and judo (35.9%), followed by taekwondo (32.5%), and lowest in boxing (21.0%) (Figure 1).

[insert Figure 1 near here]

Injury profile

Overall, the most commonly injured body region was the head and neck (35.9%), followed by the upper limb (31.1%) and lower limb (26.3%). There were distinct differences in the distribution of injury by body location across the combat sports (Table 2). The highest and lowest proportions of head and neck injuries were observed in boxing (62.1%) and taekwondo (4.8%), respectively. Upper limb injuries were particularly frequent in judo (42.6%), while the lower limb was the most commonly injured body region in taekwondo (59.5%) and wrestling (45.5%). Overall, the most commonly injured tissue types were superficial tissue and skin (42.9%) and ligament and joint capsule (31.4%), with the most frequent types of pathology being joint sprain (31.4%), laceration and abrasion (23.2%), and contusions (19.7%). Concussion accounted for 3.2% of all recorded injuries. There were similarities and differences in the distribution of injury by type of pathology across the combat sports (Table 3). Contusion was common in all combat sports (i.e., boxing: 18.5%; judo: 16.0%; taekwondo: 28.6%; and wrestling: 21.8%). Laceration was particularly common

in boxing (41.1%), while joint sprain was predominant in judo (47.9%), taekwondo (33.3%), and wrestling (40.0%).

[insert Table 2 near here]
[insert Table 3 near here]

Risk factors for injury

Overall, there was no significant difference in IIR_{ME} between females versus males (RR_{ME} 1.06; 95%CI 0.82, 1.36), heavy versus light weight categories (RR_{ME} 0.97 [95%CI 0.76, 1.24]), or final versus preliminary tournament rounds (RR_{ME} 1.00 [95%CI 0.78, 1.27]). There were some notable differences in potential risk factors across the combat sports (Figure 3). Compared to their male counterparts, female taekwondo athletes had lower IIR_{ME} (RR_{ME} 0.69 [95%CI 0.57, 1.95]), whereas female judo athletes had higher IIR_{ME} (RR_{ME} 1.30 [95%CI 0.90, 2.03]); however, the differences were not statistically significant in either of the sports. Compared to their light weight counterparts, heavy weight judo athletes had significantly lower IIR_{ME} (RR_{ME} 0.57 [95%CI 0.33, 0.97]), whereas heavy weight boxing athletes had higher IIR_{ME} (RR_{ME} 1.32 [95%CI 0.93, 1.88]), albeit the difference was not significant in boxing. There was no significant change in IIR_{ME} in taekwondo following major rule changes (i.e., electronic scoring and more points awarded for head kicks) that were introduced after the Beijing 2008 Olympic Games (RR_{ME} 0.81 [95%CI 0.44, 1.50]). There was a three-fold increase in IIR_{ME} for male boxers after rule changes (i.e., removal of protective headguard) that were introduced after the London 2012 Olympic Games (RR_{ME} 3.00 [95%CI 2.07, 4.36]).

[insert Figure 3 near here]

Injury and performance

Overall, athletes losing a contest had significantly higher IIR_{ME} than their winning opponents (RR_{ME} 3.59 [95%CI 2.68, 4.79]). The magnitude of this effect was largest in wrestling (RR_{ME} 6.40 [95%CI 2.57, 15.91]) and smallest judo (RR_{ME} 2.67 [95%CI 1.56, 4.55]) (Figure 4).

[insert Figure 4 near here]

DISCUSSION

This study highlights important differences in the burden of injury in Olympic combat sports. On average, these athletes sustain one injury every 2.1 hours of competition, with significantly greater risk of injury in boxing, judo, and taekwondo than in wrestling. About 70% of injuries are minor, with higher proportions moderate to severe injuries in wrestling, judo, and taekwondo than in boxing.

Injury incidence

We found that Olympic combat sport athletes sustained 40.9 competition injuries per 1,000 exposures or 7.8 injuries per 1,000 minutes of exposure (469.6 injuries per 1,000 hours of exposure), which equate to 1 injury every 24 exposures or 2.1 hours of exposure, respectively. The risk of injury varied significantly between combat sports, but the relative risk of injury depended on the choice of denominator. The observed IIR_{AE}, in descending order, were 76.6 in boxing, 46.4 in taekwondo, 34.0 in judo, and 22.7 in wrestling, which suggests that the risk of injury in boxing was about 1.7 times higher than in taekwondo, 2.3 times higher than in judo, and 3.3 times higher than in wrestling. However, the duration of contests is not the same for all Olympic combat sports. When factoring the actual time at-risk, the observed IIR_{ME}, in descending order, were 9.6 in judo, 9.2 in boxing, 7.7 in taekwondo, and 4.8 in wrestling. This suggests that the risk of injury is similar in judo and boxing, which is 1.2 times higher than in taekwondo and about 2 times higher than in wrestling. The differences in relative risk outlined above underscores the importance of using injury incidence rates accounting for actual time at-risk when comparing injury risk across combat sports.

Relatively few studies have reported on injury risk in Olympic combat sports using exposure units that account for time at-risk, with IIR_{ME} estimates ranging from 13.8 to 20.4 in boxing,[17-19] 16.3 in taekwondo,[20] 10.9 in judo,[21], and 5.9.[22] The IIR_{ME} estimates in our study appear to be lower than in these previous studies. Although the reasons for the inconsistencies in IIR_{ME} estimates is unclear, it is likely to be related to variability in methodology (e.g., injury surveillance methods and operational injury definitions), study populations (e.g., level of competition, age groups, and sex), and context (e.g., competition rule changes over time).

Injury severity

The distribution of injuries by severity varied across combat sports, with the proportion of injuries resulting in >7 days absence from participation being higher in wrestling (39.6%) and judo (35.9%), followed by taekwondo (32.5%), and lowest in boxing (21.0%). Notwithstanding the limited number of previous studies reporting on the distribution of injuries by severity, the available data appear to conform with our findings. That is, while no studies have reported on the distribution of injury severity in terms of time loss in boxing or judo, one study reported that 32% of injuries in taekwondo resulted in >7 days absence from participation and one study found that 34% of injuries in wrestling required >10 days absence from participation.[20,24] It is important to note that the present study relied on estimates of time lost from participation. The higher proportion of moderate and severe injuries in judo and wrestling is likely related to the fact that knee ligament injuries feature prominently in these grappling style combat sports, in which athletes are frequently exposed to direct or indirect contact through various takedown techniques (i.e., techniques aiming to bring the opponent to the ground).[9,10,23] This suggests that injury prevention strategies specifically targeting these types injuries may be particularly important to reduce the burden of injury in judo and wrestling.

Injury profile

We have identified distinct differences in injury profiles across combat sports, which are generally consistent with those reported in previous reviews.[7-10] Differences in injury profiles across combat sports have been attributed to unique features of the sports such as competition rules (e.g., permissible techniques and targets, mandatory protective equipment).[25,26] For instance, although strikes to the head and trunk are permissible in both boxing and taekwondo, only the latter permit the use of kicks. This increases the typical distance between opponents and reduces the frequency of punching, which in turn results in fewer head impacts and more distal lower limb injuries in taekwondo compared to boxing. Another example is that, unlike the striking styles (i.e., boxing and taekwondo), the grappling styles (i.e., judo and wrestling) allow direct and indirect contact to the lower limbs through various techniques aiming to bring or pin the opponent to the ground, which explains why knee ligament injuries feature prominently in the grappling styles.[9,10,23]

Risk factors for injury

Competition rules are revised from time to time, albeit major changes are relatively infrequent. Although such rule changes are not necessarily introduced to improve athlete

safety, they are nonetheless factors that may alter the risk of injury. For instance, the post-Beijing 2008 rule changes in taekwondo were introduced to improve transparency of the scoring system and make the sport more entertaining for audiences. To encourage taekwondo athletes deploying more head kicks, the rule changes involved increasing the number of points awarded for head kicks and decreasing the minimum impact required to score points from head kicks. Contrary to initial concerns about the potential for increasing the risk of injury, our data showed a slight decrease in injury rates after the rule change. A possible explanation for this observation is that although the frequency of head kicks has increased, a greater emphasis on speed has resulted in a general decrease in the impact forces imparted during the delivery of head kicks. Unlike the rule change in taekwondo, the decision to eliminate protective headguards in men's boxing was based on safety concerns. That is, a cross-sectional study conducted by the amateur boxing governing body claimed that match stoppages due to repeated head blows were less common when headguards were not worn.[27] The rule change has been controversial, partly because although the rate of match stoppages due to repeated head blows decreased by 43%, the rate of lacerations increased 430%; and partly because of the paradox created by eliminating headguards in men's, but not women's, boxing without any clear rationale for the disparate practice. Our data showed a three-fold increase in overall injury risk for male boxers after the elimination of protective headguards. This suggests that carefully designed research is needed to elucidate the relationship between injury risk and protective headguards in both women's and men's amateur boxing.

Injury and performance

Unsurprisingly, the outcome of contests was strongly associated with occurrence of injury, with losing athletes having a 3.6 times higher injury incidence rate compared to their winning opponents. Although the direction of this relationship cannot be established in this study, it seems more plausible that sustaining an injury results in poor performance rather than poor performance increasing the risk of injury. If so, then it follows that avoiding injury is key to improved performance and athletic success. This view concurs with studies concluding that injuries have a detrimental impact athletic success and that injury prevention should therefore be a priority for maximising athletic performance.[28,29]

Strengths and limitations

This is the first study to compare the epidemiology of competition injuries in Olympic combat sports using directly comparable injury and exposure data. Injury data were obtained from a high-quality, multisport injury surveillance system, which ensured consist and standardised recording of injuries for all combat sports. Furthermore, actual time exposed to risk of injury was obtained from official tournament records, which facilitated comparison of injury incidence rates per unit time exposed. Notwithstanding these strengths, this research has some limitations. Firstly, injuries are likely to be underreported, thereby underestimating the true risk of injury in Olympic combat sports. Although the rate of returned daily injury report forms was very high at the three Olympic Games,[12-14] there is good reason to believe that not all injuries were reported, in particular less severe injuries. That is, injured athletes do not always seek medical attention, especially for injuries without time loss,[30-32] and all NOC medical teams may not have been fully aware of the broad injury definition applied in the IOC injury surveillance system.[13] However, we have no reason to believe reporting varied by type of combat sport, which means our measures of relative risk are unlikely to be impacted by underreporting. Secondly, although NOC and LOC medical teams are comprised of highly experienced sports medicine practitioners, the accuracy and internal validity of their reported data is not known. Thirdly, injury severity was based on estimates of time loss provided at the time the athletes sought medical attention, the accuracy of the estimated time loss is unknown. Fourthly, although we were unable to map all recorded injuries to a specific exposure, injuries could always be attributed to a particular combat sport. This may have decreased the statistical power in our rate ratio calculations for various risk factors (i.e., sex, tournament round, and contest outcome), but it has not impacted our estimates of relative risk of injury between combat sports. Lastly, this study included competition data from three Olympic Games, which may limit the generalisability of the findings. It is possible that the injury risk and profile is different in the training-setting and among combat sport athletes competing at non-Olympic tournaments (i.e., at the local, regional, national levels) due to potential differences in level of fitness, training load, technical abilities, and competition experience. It is also possible that the injury risk and profile is different at other top-level competitions (i.e., World Championships) due to differences in tournament schedules (e.g., number of weight divisions and average number of exposures per athlete). Our findings should be interpreted in the light of these limitations.

Recommendations and implications

Future studies of injuries in combat sports are strongly recommended to adhere to definitions and data collection procedures outlined in the recent IOC consensus statement on methods for recording and reporting epidemiological data from injury and illness surveillance in sports.[15] Injury incidence rates should be reported using both per athlete exposure and actual time at-risk (e.g., minutes of exposure) to facilitate comparisons within and across combat sports. Injury severity should be measured and reported using the actual number of days absent from competition and training. Classification of injury diagnoses (i.e., by anatomical location and type of injury) should adhere to standardised sports-specific coding systems such as the revised versions of the Sport Medicine Diagnostic Coding System (SMDCS) or the Orchard Sports Injury and Illness Classification System (OSIICS).[15,33]

We hope that our findings will facilitate the development and implementation of evidence-informed injury prevention efforts and drive policy change in Olympic combat sports, thereby making these sports safer and more enjoyable for athletes. Our findings show that major rule changes can significantly impact the risk of injury, which suggests that combat sport governing bodies could deliberately improve the safety of their sports by implementing new competition rules designed to reduce injury risk. However, combat sport governing bodies need to mindful of the potential for unintended consequences when implementing new competition rules and are therefore strongly encouraged to partner with sports injury prevention and implementation scientists when planning to introduce major rule changes.

Major rule changes notwithstanding, there is a need for investigating a broader range of risk factors and injury mechanisms in combat sports, especially potentially modifiable factors that may be targeted by injury prevention interventions. For instance, although the relationship between training load and injury is well established in the sports injury literature,[34] it remains largely unexplored in context of combat sports. Another important factor to be considered is the rapid weight loss practices that are prevalent in the combat sports.[35] Previous studies have documented a range of potential negative health implications associated with rapid weight loss practices, including severe dehydration resulting in acute cardiovascular problems (e.g., ischaemic heart disease and stroke) and increased susceptibility to traumatic brain injury.[36,37] There are even documented cases of deaths linked to rapid weight loss practices in combat sports.[38] Further research to elucidate the relationship between rapid weight loss practices and injury risk in combat sports is warranted. For international competitions such as the Olympic Games, it would also be useful to

consider the potential impact of long-distance air travel (e.g., recovery, sleep disruption, and acclimation) on injury risk. Although the association between of travel and injury risk has been investigated in other sports,[39,40] it remains unexplored in context of combat sports. Finally, it is especially important to consider and account for the multifactorial, dynamic, and complex nature of sports injury causation. Future studies are therefore strongly encouraged to adopt frameworks that incorporates this inherent complexity.[41-44]

CONCLUSION

Olympic combat sport athletes sustained, on average, 1 injury every 2.1 hours of competition. The risk of injury was significantly higher in boxing, judo, and taekwondo than in wrestling. About 30% of injuries sustained during competition resulted in >7 days absence from participation, with higher proportions in wrestling, judo, and taekwondo than in boxing. Overall, there was no significant difference in injury risk by sex, weight category, or tournament round, but defeated athletes were more than three times more likely to sustain an injury compared to their winning opponents. There is a need for identifying modifiable risk factors for injury in Olympic combat sports, which in turn can be targeted by injury prevention initiatives to reduce the burden of injury among combat sport athletes.

ACKNOWLEDGEMENTS

FOOTNOTES

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Contributors RPL, TS and LE conceived the study. TS and LE provided the injury data. RPL, AA, and IR collated the exposure data. RPL conducted the analysis and wrote the first draft of the manuscript. RPL, TS, and LE interpreted the findings and reviewed and edited the manuscript. All authors approved the final manuscript.

Competing interests RPL, AA, and IR declare that they have no potential conflicts of interest that are directly relevant to this study. TS and LE work in the Medical and Scientific Department of the IOC as Scientific Manager and Head of Scientific Activities, respectively.

Patient consent Not required.

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FIGURE LEGENDS

Figure 1. Distribution of injuries by severity category for each combat sport.

Figure 2. Risk matrix plot of injury burden for each combat sport.

Figure 3. Forest plots of injury incidence rate ratios per 1,000 minutes of exposure for each combat sport by sex (A), weight category (B), tournament round (C), and pre/post-major rule changes (D).

Figure 4. Forest plot of injury incidence rate ratios per 1,000 minutes of exposure for each combat sport by contest outcome.

Table 1. Overview of injury and exposure data and injury incidence rates for each combat sport.

	Boxing	Judo	Taekwondo	Wrestling
Injuries, n	124	94	42	55
Athlete registrations, n	857	1,163	384	1,008
Athlete exposures, n	1,618	2,762	906	2,426
Minutes of exposure, n	13,536	9,807	5,430	11,476
Injury incidence rate per 100 athlete registrations (95%CI)	14.5 (12.0, 17.3)	8.1 (6.5, 9.9)	10.9 (7.9, 14.8)	5.5 (4.1, 7.1)
Injury incidence rate per 1,000 athlete exposures (95%CI)	76.6 (63.7, 91.4)	34.0 (27.5, 41.7)	46.4 (33.4, 62.7)	22.7 (17.1, 29.5)
Injury incidence rate per 1,000 minutes of exposure (95%CI)	9.2 (7.6, 10.9)	9.6 (7.8, 11.7)	7.7 (5.6, 10.5)	4.8 (3.6, 6.2)

Table 2. Frequency (%) of injuries by body region and area for each combat sport.

Region/Area	Boxing (n=124)	Judo (n=94)	Taekwondo (n42)	Wrestling (n=55)
Head and neck	77 (62.1)	24 (25.5)	2 (4.8)	10 (18.2)
Head	75 (60.5)	22 (23.4)	2 (4.8)	10 (18.2)
Neck	2 (1.6)	2 (2.1)	-	-
Trunk	10 (8.1)	3 (3.2)	2 (4.8)	6 (10.9)
Chest	2 (1.6)	2 (2.1)	-	4 (7.3)
Abdomen	1 (0.8)	-	-	-
Thoracic spine	4 (3.2)	1 (1.1)	-	1 (1.8)
Lumbosacral	3 (2.4)	-	2 (4.8)	1 (1.8)
Upper limb	31 (25.0)	40 (42.6)	13 (31.0)	14 (25.5)
Shoulder	6 (4.8)	11 (11.7)	2 (4.8)	7 (12.7)
Upper arm	2 (1.6)	1 (1.1)	-	-
Elbow	8 (6.5)	18 (19.1)	-	3 (5.5.)
Forearm	6 (4.8)	-	-	-
Wrist	6 (4.8)	8 (8.5)	8 (19.0)	-
Hand	3 (2.4)	2 (2.1)	3 (7.1)	4 (7.3)
Lower limb	6 (4.8)	27 (28.7)	25 (59.5)	25 (45.5)
Hip/groin	-	1 (1.1)	-	-
Thigh	-	4 (4.3)	7 (16.7)	4 (7.3)
Knee	2 (1.6)	16 (17.0)	7 (16.7)	20 (36.4)
Lower leg	-	-	1 (2.4)	1 (1.8)
Ankle	4 (3.2)	3 (3.2)	5 (11.9)	-
Foot	-	3 (3.2)	5 (9.5)	-

Table 3. Frequency (%) of injuries by tissue and pathology type for each combat sport.

Tissue/Pathology type	Boxing (n=124)	Judo (n=94)	Taekwondo (n42)	Wrestling (n=55)
Muscle / Tendon	*9 (7.3)*	*8 (8.5)*	*5 (11.9)*	*12 (21.8)*
Muscle injury	7 (5.6)	5 (5.3)	4 (9.5)	5 (9.1)
Tendinopathy	2 (1.6)	1 (1.1)	1 (2.4)	6 (10.9)
Tendon rupture	-	2 (2.1)	-	1 (1.8)
Nervous	*8 (6.5)*	*1 (1.1)*	*2 (4.8)*	*-*
Brain and/or spinal cord injury	8 (6.5)	1 (1.1)	1 (2.4)	-
Peripheral nerve injury	-	-	1 (2.4)	-
Bone	*6 (4.8)*	*2 (2.1)*	*6 (14.3)*	*2 (3.6)*
Fracture	5 (4.0)	2 (2.1)	6 (14.3)	2 (3.6)
Bone stress injury	1 (0.8)	-	-	-
Cartilage / Synovium / Bursa	*3 (2.4)*	*4 (4.3)*	*-*	*2 (3.6)*
Cartilage	1 (0.8)	3 (3.2)	-	1 (1.8)
Arthritis / Synovitis / Bursitis	2 (1.6)	1 (1.1)	-	1 (1.8)
Ligament / Joint capsule	*18 (14.5)*	*45 (47.9)*	*14 (33.3)*	*22 (40.0)*
Joint sprain	18 (14.5)	45 (47.9)	14 (33.3)	22 (40.0)
Superficial tissues / Skin	*74 (59.7)*	*32 (34.0)*	*13 (31.0)*	*16 (29.1)*
Contusion (superficial)	23 (18.5)	15 (16.0)	12 (28.6)	12 (21.8)
Laceration / Abrasion	51 (41.1)	17 (18.1)	1 (2.4)	4 (7.3)
Other / Unknown / Unspecified	*6 (4.8)*	*2 (2.1)*	*2 (4.8)*	*1 (1.8)*