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New sports, COVID-19 and the heat: Sports injuries and illnesses in the Tokyo 2020 Summer Olympics

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Competing Interests:

Torbjørn Soligard works as Scientific Manager in the Medical & Scientific Department of the International Olympic Committee. Kathrin Steffen is co-editor of the British Journal of Sports Medicine – Injury Prevention & Health Protection. Margo Mountjoy is Deputy Editor of the British Journal of Sports Medicine. Richard Budgett is Director of the Medical and Scientific Department of the International Olympic Committee. Lars Engebretsen is Head of Scientific Activities in the Medical & Scientific Department of the International Olympic Committee, and Editor of the British Journal of Sports Medicine and Associate Editor of Journal of Bone and Joint Surgery.

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Abstract

Objective: To describe the incidence of injuries and illnesses sustained during the Tokyo Summer Olympic Games from 23 July to 8 August 2021.

Methods: We recorded the daily number of athlete injuries and illnesses 1) through the reporting of all National Olympic Committee (NOC) medical teams and 2) in the polyclinic and medical venues by the Tokyo 2020 medical staff.

Results: In total, 11 315 athletes (5423 women, 48%; 5892 men, 52%) from 206 NOCs were followed prospectively for the occurrence of injury and illness. NOC and Tokyo 2020 medical staff reported 1035 injuries and 438 illnesses, equalling 9.1 injuries and 3.9 illnesses per 100 athletes over the 17-day period. Altogether, 9% of the athletes incurred at least one injury and 4% at least one illness. The injury incidence was highest in boxing (27%), BMX racing (27%), BMX freestyle (22%), skateboarding (21%), karate (19%), and handball (18%), of which both BMX freestyle and skateboarding were new events, and lowest in diving, road cycling, rowing, marathon swimming and shooting (1-2%). Marathon and artistic swimming presented the highest illness incidences (both 8%), followed by skateboarding and karate (both 7%). In the study period, COVID-19 affected 18 athletes, accounting for 4% of all illnesses and 0.16% of all athletes. Exertional heat illness affected 78 athletes (18% of all illnesses, 0.7% of all athletes), the majority (88%) resulting in no time loss from sport.

Conclusion: Overall, 9% of the athletes incurred an injury and 4% an illness during the Games. Comprehensive countermeasures helped mitigate both COVID-19 and exertional heat illnesses.

What is already known on this topic

- Elite athletes gain a number of health benefits, but run a high risk of musculoskeletal injuries and other disorders during and after their sporting careers

What this study adds

- Overall, 9% and 4% of the athletes incurred at least one injury or illness, respectively, during the Tokyo 2020 Olympic Games
- Boxing (27%), BMX racing (27%), BMX freestyle (22%), skateboarding (21%), karate (19%), and handball (18%) were the sports with the highest incidences of injury
- COVID-19 and a hot and humid environment presented considerable challenges for the athletes and the organisation of the Games, but both were mitigated through comprehensive countermeasures

How this study might affect research, practice or policy

- Athlete medical staff and event organisers can plan and optimise their health care provision, and, more importantly, prevention measures according to the clinical presentation and risk profile of their athlete populations

Introduction

Reaching the highest level in sport requires athletes to commit to thousands of hours of deliberate and intense training. The extreme nature of their line of work, striving to outperform their peers through relentlessly pushing their physical and mental boundaries,[1] also means that many oscillate between being *either almost injured or injured* throughout their careers. While athletes benefit from greater life expectancy and lower risk of chronic disease and hospital admission compared to the general population,[2–5] they do run a high risk of injuries and musculoskeletal disorders throughout[1,6–11] and after the end[12–15] of their sporting career.

Protecting the health of the athletes is one of the main priorities of the International Olympic Committee (IOC),[16] and the IOC has surveyed the sports injuries and illnesses in every Olympic Games since Beijing 2008.[6–11] The overall proportion of injured athletes has ranged from 10% to 14% and ill athletes from 5% to 9%; however, there have been large variations between sports. The Tokyo 2020 Summer Olympics introduced several new sports and disciplines, including baseball/softball, karate, skateboarding, sport climbing, surfing, 3x3 basketball and BMX freestyle.

The main challenge facing the Tokyo Olympics was the outbreak of the global COVID-19 pandemic, which had forced the postponement of the Games by one year. Ensuring the successful running of the Olympic Games while at the same time protecting the health and safety of both athletes and the general public was a monumental and unprecedented undertaking.[17–19] In addition, a hot and humid Tokyo summer presented both athletes and the event organisers with an additional challenge from both a sporting and health protection point of view.[20–22]

Our aim in this study was to describe the incidence and characteristics of the sports injuries and illnesses occurring during the Tokyo 2020 Summer Olympics.

Methods

We employed the IOC injury and illness surveillance system for multi-sport events in this prospective cohort study as used in prior Games.[23] Notably, the 2020 IOC consensus statement on methods for recording and reporting injury and illness data in sport was not published until after preparation for this study was completed.[24] We invited all National Olympic Committee (NOC) medical teams to report the daily occurrence (or non-occurrence) of athlete injuries and illnesses using an electronic report form (side module of General Electric Athlete Management Solution; GE AMS). Concurrently, we retrieved the same information on all athletes treated for injuries and illnesses in the polyclinic and all other medical venues operated by the Tokyo Organising Committee of the Olympic and Paralympic Games (Tokyo 2020 / OCOG) medical staff. These data were collected through an electronic medical record system (GE AMS).

Implementation

The day before the opening of the Games we organised a meeting for all NOC medical staff. At this meeting we informed them about the protocol, answered questions, created user accounts for the GE AMS injury and illness reporting system, and distributed tablet computers to facilitate their daily reporting.

Throughout the data collection, we actively followed up with frequent visits the NOCs whose team sizes were 10 athletes or larger (respecting COVID-19 countermeasures) and electronic contact to address any questions and encourage continuous reporting during the games. We recorded the response rate (and injuries and illnesses) of all the participating NOCs.

Definition of injury and illness

We defined injuries and illnesses as new (pre-existing, not fully rehabilitated conditions were not recorded) or recurring (athletes having returned to full participation after a previous condition) incurred in competition or training during the period between the Opening and Closing Ceremonies of the Olympic Games Tokyo 2020 (23 July - 8 August 2021) receiving medical attention, regardless of the consequences with respect to absence from competition or training. Injuries comprised musculoskeletal complaints, concussions, and other non-musculoskeletal trauma. Illnesses were defined as complaints or disorders not related to injury. In cases where a single incident caused multiple injury types, we recorded only the most severe diagnosis – as determined by our research team based on all available clinical data – for analysis. We define injury and illness severity by the number of estimated days lost from training or competition. In the interest of presenting complete data on COVID-19 in athletes at the Games, we also report all confirmed cases occurring before the opening of the Games (from the day the athletes arrived at the airport in Tokyo), but do not include these in the analyses overall and per sport (to avoid skewing the results in comparison to past and future Games).

Injury and illness report form

Our injury and illness report form followed the template of that used in the Vancouver 2010, London 2012, Sochi 2014, Rio 2016, and PyeongChang 2018 Olympic Games. With respect to injuries, we recorded the following data: accreditation number, name, sport and event, whether the injury occurred in competition or training, date and time, body part, type, cause and estimated time lost from competition or training. We recorded data on illnesses in a similar fashion: accreditation number, sport and event, date, affected system, main symptom(s), cause and estimated time loss.

We provided instructions and examples on how to complete the form correctly. Furthermore, the report form was available in nine languages: English, French, Arabic, Chinese, German, Japanese, Korean, Russian, and Spanish.

Confidentiality and ethical approval

In addition to the aforementioned variables, we queried the IOC athlete database for the age and sex of the injured or ill athlete. We treated all information confidentially, and de-identified our database after the Games, ensuring anonymity of all athletes.

The study was reviewed by the Medical Research Ethics Committee of the South-Eastern Norway Regional Health Authority (2011/388).

Patient and Public Involvement

Patients were not involved in planning or execution of the study. Representatives of the patients (the athletes) will be invited to help interpret the results and their relevance and potential for future injury and illness prevention measures.

Data analysis

In cases where athletes were treated for the same condition by both the NOC and Tokyo 2020 medical staff, we retained the most complete data source. Unless more precise clinical data were available, we set the estimated days of absence from sport for confirmed COVID-19 cases to ten days, based on the average isolation time in place during the Games.

We calculated the summary measures of injury and illness incidences (*i*) according to the formula $i=n/e$, where n is the number of injuries or illnesses in competition, training or in total during the study period and e the respective number of exposed (participating) athletes; with incidence proportions presented as injuries/illnesses per 100 athletes. We also calculated the summary measures of injury and illnesses per 1000 athlete-days, where athlete-days correspond to the total number of athletes multiplied by 17 days. We calculated confidence intervals of the risk ratio (RR) of the number of injuries or illnesses between two groups by a simple Poisson model, assuming constant hazard per group and adjusting for sport, sex, age, and/or NOC size (by the number of athletes) where appropriate. We present injury and illness incidences as means and risk ratios with 95% confidence intervals. We regarded two-tailed p values <0.05 as significant.

Results

In total, 11 315 athletes took part in the Tokyo Olympic Games. Of these, 5423 were women (48%) and 5892 men (52%). Ten athletes participated in two different sports, giving a total of 11 325 athlete exposures to injury or illness.

Throughout the 17 days of the Games, the 206 NOCs submitted 1866 of maximal 3502 daily reports (53%; 94 countries did not submit any data) (Table 1). The response rate of the 108 NOCs with ≥10 participating athletes (accounting for 96% of all the athletes) was 95% (1752 of 1836 reports).

Table 1. Response rates, injuries and illnesses in NOCs of different sizes (measured by number of athletes)

	<10	10-49	50-99	>99	All
Number of NOCs (athletes)	98 (457)	56 (1454)	20 (1438)	32 (7961)	206 (11 315[a])
Injuries (injuries per 100 athletes)	45 (9.8)	191 (13.1)	178 (12.4)	607 (7.6)	1035 (9.1)
Illnesses (illnesses per 100 athletes)	39 (8.5)	93 (6.3)	56 (3.8)	250 (3.1)	438 (3.9)
Daily reports submitted (%)	114 (7%)	883 (93%)	333 (98%)	536 (99%)	1866 (53%)
Recorded by both NOC and OCOG					
Injuries (%)	0 (0%)	25 (13%)	28 (16%)	77 (13%)	134 (13%)
Illnesses (%)	0 (0%)	6 (7%)	5 (9%)	7 (3%)	18 (4%)
Recorded only by NOCs					
Injuries (%)	1 (2%)	60 (31%)	70 (39%)	271 (45%)	404 (39%)
Illnesses (%)	1 (3%)	23 (25%)	25 (45%)	128 (51%)	177 (40%)
Recorded only by OCOG					
Injuries (%)	44 (98%)	106 (56%)	80 (45%)	259 (43%)	497 (48%)
Illnesses (%)	38 (97%)	64 (69%)	26 (46%)	115 (46%)	243 (56%)

[a]10 double-starters excluded.

Injuries overall, by sport and sex

We recorded a total of 1035 injuries, equalling 9.1 injuries [95% CI: 8.6-9.7] per 100 participating athletes. This corresponds to 5.4 injuries per 1000 athlete-days. Overall, 9% (n=964) of the athletes sustained at least one injury. Of these, 45 athletes sustained two injuries, and one athlete sustained three injuries.

Figure 1 shows the incidence proportion of injured athletes in each sport (additional details are available in Online appendix 1). The incidence of injury was highest in boxing (27.1 injuries [95% CI 21.1 to 33.1] per 100 athletes), BMX racing (27.1 [12.4-41.8]), BMX freestyle (22.2 [0.4-44.0]), skateboarding (21.0 [11.0-31.0]), karate (18.5 [9.1-27.9]), and handball (17.8 [13.4-22.3]), and lowest in diving, road cycling, rowing, marathon swimming and shooting (ranging from 1 to 2 injuries per 100 athletes).

When adjusting for sport, age and NOC size, there was no difference in overall injury incidence between women (8.6 injuries [95% CI: 7.8-9.4] per 100 athletes) and men (9.6 [8.8-10.4], RR=0.93 [0.83-1.06], Online appendix 1). However, female athletes were at significantly higher risk of injury in artistic gymnastics (RR=3.20 [1.17-8.74]), while at lower risk in baseball/softball (RR=0.19 [0.04-0.81]) and boxing (RR=0.43 [0.24-0.75]).

Severity of injuries

While 56% of the injuries were estimated to result in no time loss from sport (n=583), 44% (n=124) were expected to entail ≥1 day of time loss from competition or training (Online appendix 1). It was estimated that 24% of the injuries (n=247) would result in an absence from sports from 1 to 7 days, 11% (n=113) in an absence from 8 to 28 days, and 9% (n=92) in an absence for more than 28 days. Figure 1 shows the incidence of injuries estimated to lead to ≥1 day and >7 days of absence in each sport. Box 1 presents the details of the 205 injuries with >7 days of time loss.

Box 1. Information on the 205 injuries with estimated absence >7 days, with the sports with the highest numbers in brackets.

- 43 muscle strains grade 1 or 2 (25 in athletics, 2 each in rugby, weightlifting, fencing and tennis)
- 33 ligament sprains grade 1 or 2 (7 in judo, 6 in wrestling, 3 in football, 2 each in indoor volleyball and athletics)
- 20 acute fractures (5 in boxing, 3 in rugby, 2 in taekwondo, 2 in track cycling)
- 17 joint dislocations/subluxations (5 in handball, 3 in rugby, 2 in judo)
- 13 bone contusions (3 in boxing, 2 each in judo and taekwondo)
- 12 muscle ruptures grade 3 (5 in athletics, 3 in football)
- 11 lesions of meniscus or cartilage (2 in fencing)

- 10 ligament ruptures grade 3 (2 each in judo, rugby and team handball)
- 7 stress fractures/reactions (5 in athletics)
- 6 skin lesions/lacerations (3 in boxing, 2 in athletics)
- 6 concussions (2 in hockey)
- 5 tendon ruptures grade 3 (3 in athletics)
- 5 tendinopathies (3 in athletics)
- 4 tendon sprains grade 1 or 2 (2 in athletics)
- 4 joint synovitis/arthritis/bursitis
- 3 muscle contusions/haematoma
- 1 fasciitis/aponeurosis injury
- 1 joint impingement

Details missing for four injuries

Location and type of injuries

The most commonly injured locations were the knee (n=114), posterior thigh (n=89), shoulder (n=88), ankle (n=86), and face (including eyes, ears and nose; n=80). The most common injury types were skin laceration/lesion/abrasion (n=133), muscle strain grade 1 or 2 (n=119), and ligament sprain grade 1 or 2 (n=113). The distributions of injury locations and injury types per sport are presented in Online appendix 2 and 3, respectively.

Causes, mechanisms and onset of injury

While 77% (n=793) of the injuries occurred acutely, 12% (n=121) and 10% (n=101) were chronic or recurrent, respectively (information missing for 20 injuries). In terms of aetiology, the most commonly reported injury mechanisms were contact with another athlete (26%), non-contact trauma (20%), overuse with sudden onset (14%), and overuse with gradual onset (12%); details for each sport are available in Online appendix 4.

Fifty-eight percent of the injuries were sustained in competition, 34% during training, and 7% during warm up or cool down (information missing for 11 injuries; details for each sport are presented in Online appendix 1).

Illnesses overall, by sex, sport and severity

Among the 11 325 athletes, a total of 438 illnesses were reported, resulting in 3.9 illnesses [95% CI: 3.5-4.2] per 100 athletes. This corresponds to 2.3 illnesses per 1000 athlete-days. On average, 4% (n=420) of the athletes incurred an illness, as 16 athletes incurred two illnesses and one athlete reported three illnesses. When controlling for sport, age and NOC size, women (4.6 illnesses [4.0-5.1] per 100 athletes) were at significantly greater risk of experiencing an illness than men (3.2 [2.8-3.7], RR=1.51 [1.25-1.82], Online appendix 1).

Figure 2 shows the incidence proportion of illness in each sport (additional details are available in Online appendix 1). Marathon swimming had the highest illness incidence (7.8 illnesses [95% CI 0.2-15.5] per 100 athletes), followed by artistic swimming (7.7 [2.4-13.0]), skateboarding (7.4 [1.5-13.3]), and karate (7.4 [1.5-13.3]). Conversely, no illnesses occurred in 3x3 basketball, mountain bike cycling, and modern pentathlon.

One in five illnesses (n=80, 18%) were expected to result in absence from training or competition. In artistic swimming, five out of the eight illnesses were estimated to entail >7 days of absence (Online appendix 1).

Affected system, aetiology of illness, and COVID-19

The most affected organ systems/regions were the dermatologic (n=83, 19%), thermoregulatory (n=78, 18%), respiratory (n=75, 17%), and gastrointestinal (n=63, 14%) systems.

Of the 75 respiratory illnesses, 45 were caused by infection (10% of all illnesses, 0.4% of the athletes incurred a respiratory infection), of which 18, in turn, were SARS-CoV-2 infections (4% of all illnesses, 0.16% of the athletes). In addition to the cases occurring during the study period (23 July - 8 August 2021), there were 15 confirmed cases occurring before the Games started (ie, from arrival at the airport until the Opening Ceremony of the Games), giving a total of 33 cases of COVID-19 in athletes (0.29% of the athletes).

With respect to the thermoregulatory illnesses, all reported cases (n=78, 18% of all illnesses, affecting 0.7% of all athletes across all sports) were exercise-induced heat illnesses; the majority resulting in no time loss from sport (n=69, 88%). Nine cases were estimated to lead to time loss from sport: seven (9% of all heat illnesses) entailing one day of absence and two (3% of all heat illnesses) entailing three days of absence.

The distribution of affected systems, main symptoms and aetiology of illness per sport are presented in Online appendices 5, 6 and 7, respectively.

Data sources, and injuries and illnesses per NOC size

Only 13% of all injuries and 4% of all illnesses were captured by both the NOCs and the Tokyo 2020 staff. While 39% of the injuries and 40% of the illnesses were recorded solely by the NOCs, 48% and 56% of the injuries and illnesses, respectively, were recorded solely by the Tokyo 2020 staff (Table 1).

The incidence of injury and illness tended to be lowest for NOCs with >99 athletes, and when adjusting for sport, sex and age, there was an inverse relationship between NOC size and the incidence of illness, with athletes from smaller NOCs suffering more illnesses (NOCs with <10 athletes: 8.5 [5.9-11.2] illnesses per 100 athletes vs. NOCs with >99 athletes: 3.1 [2.8-3.5] illnesses per 100 athletes (RR=2.97 [2.12-4.18]).

Discussion

Injuries in existing and new Olympic sports

The aim of the present paper was to describe the athlete injuries and illnesses which occurred during the Tokyo 2020 Olympic Games. The incidence of injury in the Tokyo Olympics (9%) was comparable to those in the Summer Games of Beijing 2008 (10%),[11] London 2012 (11%),[9] and Rio 2016 (8%).[7]

When comparing each sport in Tokyo 2020 with Rio 2016, the injury incidences in Tokyo were higher in table tennis (12% vs. 3% of the athletes injured), but lower in diving (1% vs 9%), water polo (11% vs 19%), mountain biking (7% vs. 24%), road cycling (2% vs. 6%), football (8% vs. 15%), and tennis (4% vs. 11%).

Many of the new sports and disciplines on the Olympic programme presented high injury incidences. Of all the sports in Tokyo, BMX freestyle had the third highest injury incidence (22% of the athletes injured), skateboarding the fourth highest (21%) and karate the fifth highest (19%). Sport climbing (15%), surfing (13%), 3x3 basketball (11%), and baseball/softball (8%) placed around the middle third in terms of injury incidences. BMX freestyle, karate, sport climbing and 3x3 basketball were tested four years earlier during the Buenos Aires 2018 Youth Olympic Games. There, the incidence proportions where 13% in karate, 2% in sport climbing, and 18% in 3x3 basketball (data unavailable for BMX freestyle).[25]

A change in injury incidence can result from a multitude of factors, including but not limited to changes in the composition of the Olympic Games programme, environmental and weather conditions, venue or track design, competition rules, equipment, awareness and adherence to injury prevention training, injury and illness recording methods, and in the skill level and adherence of the medical staff recording the data.[26,27] This emphasizes the importance of on-going, longitudinal monitoring of injuries and illnesses as such variables may change over time.

COVID-19 in the Games

The Tokyo Olympic Games were postponed by one year due to the outbreak of the global COVID-19 pandemic in early 2020. By spring 2021, based on comprehensive collaboration between Tokyo 2020, the IOC, IPC, Government of Japan, Tokyo Metropolitan Government, a designated task force of scientific experts and organisations from across the world, the Tokyo Olympic Games playbooks were developed and implemented.[28] These COVID-19 mitigation policies and regulations outlined the responsibilities of all Games participants starting 14 days before travelling to the Games, when entering Japan, at the Games, and when leaving Japan. Key public health principles included mandated mask wearing; minimisation of physical interaction; testing, tracing and isolating; and enhanced personal hygiene (hand washing). Athletes from all participating NOCs were also offered vaccine doses ahead of the Games, with a vaccination rate of 85% among Olympic Village residents.[29] In terms of testing, participants were required to provide proof of two negative polymerase chain reaction (PCR) tests before departing for Tokyo, another negative test upon arrival, and then daily screening tests throughout the Games. The goals of these COVID-19 countermeasures were to ensure both the successful running of the Games and the safety and health of Games participants and of the people of Japan.

The effectiveness of the countermeasures is reflected in our results. The overall incidence of illness (3.9 illnesses per 100 athletes) was the lowest we have recorded in the Games; lower than in PyeongChang 2018 (9.4),[6] Rio 2016 (5.4),[7] Sochi 2014 (8.9),[8] London 2012 (7.2),[9] and Vancouver 2010 (7.2).[10] This effect was induced primarily by a substantial reduction in respiratory infections (0.4% of the athletes incurred a respiratory infection) compared with all previous Games (4.8% in PyeongChang, 1.9% in Rio, 4.2% in Sochi, 1.9% in London, 1.1% in Vancouver). Importantly, only a small fraction of the participating athletes contracted COVID-19 (0.16% of the athletes, 0.29% of the athletes if including cases reported before the Opening Ceremony of the Games), of which all cases were imported as athletes arrived in Japan, with no spread to the local population.[30] While contracting COVID-19 was potentially devastating for some of the athletes in question as the required time in isolation prevented their possible lifetime Olympic participation, the low number of COVID-19 positives was a result of the concerted countermeasures by all stakeholders involved, allowing the successful running of the Games.

Exertional heat illnesses during the Games

During the Olympic Games, Tokyo experienced high ambient temperatures (>30°C) and relative humidity (>70%),[31] limiting both the convective and evaporative capacity of the athletes to dissipate heat. It has been shown that intense and prolonged exercise under such conditions can lead some athletes to reach core body temperatures exceeding 40ºC.[32] Educational material on heat acclimatisation – one of the most efficient countermeasures to protect the athlete’s health and performance before competing in a hot environment[33] – was developed and widely circulated to the athletes to aid their preparation for the Games.[34]

Training in the heat for about two weeks triggers physiological adaptations allowing for better thermoregulation, reducing the cardiovascular stress and increasing the exercise capacity in the heat.[35] Prior to the Games, two events (marathon and race walking) were relocated 800 km north to Sapporo, which is normally 4-5°C cooler than Tokyo. However, during Games time, it was equally hot and humid there.[31] Other events were rescheduled to cooler mornings or evenings (eg, women's football final). There were also a range of important venue heat mitigation strategies in place before, during, and after competition, including the provision of hydration, shading, air conditioning, fans, ice packs, mist sprays, and pre-cooling and recovery ice baths. In terms of medical management, specific medical algorithms were developed for high heat stress venues with the goal of early recognition and diagnosis, rapid on-site cooling and advanced clinical care.[36] While we nonetheless recorded 78 cases of exertional heat illness in the Games – including diagnoses of heat stroke, exhaustion, syncope, and heat-related muscle cramps – the mitigation measures likely played a crucial role in reducing their severity, with the majority (88%) being mild in nature with no estimated time loss from sport.

Limitations

While our methodology closely followed the 2020 IOC consensus statement on the recording and reporting of sport injuries and illnesses,[24] there were some differences in the taxonomy of data variables (such as for injury types and illness organ systems). By the time the 2020 IOC consensus was published, our study preparations had come too far (including electronic medical record software development, system documentation, translations to other languages, and medical staff training) to economically justify additional changes.

In studies on sports injury, it is usually recommended to express incidences using a measure of time exposed to risk as the denominator.[24,37] However, considering the inherent complexity and size of the Olympic Games, this was not feasible in the present study. Instead, we expressed the injuries or illnesses as the number of new cases per 100 exposed athletes (incidence proportion). This approach erroneously assumes that the frequencies and lengths of exposure are identical in all sports and that the number of athletes at risk in each NOC is constant throughout the Games, potentially resulting in an overestimation of exposure and an accompanying underestimation of injury and illness incidence. Interpretation of differences in injury incidences or patterns, and comparisons to other studies must therefore be made with caution.

In the current study we included new or recurring injuries or illnesses receiving medical attention. By using this definition, gradual onset and less serious health problems may be overlooked, since they do not always require medical attention,[24,38–40] albeit our results show that the majority of reported injuries and illnesses were estimated to not entail any time loss.

Unless more precise clinical data were available, we set the estimated days of absence from sport for confirmed COVID-19 cases to ten days, based on the average isolation time in place during the Games. In cases where symptoms fully resolved either before or after the ten days had passed this would either overestimate or underestimate, respectively, the reported severity.

We asked both the NOC and the Tokyo 2020 medical personnel to record all injuries and illnesses for all athletes seen; however, only 13% of the injuries and a mere 4% of the illnesses were captured by both, underlining the importance of recording data from both groups. As it is possible that some cases were captured neither by the NOCs nor the Tokyo medical staff, our results likely underestimate the true incidence of injuries and illnesses.

Clinical implications

We have presented the injury and illness incidence proportions (Figure 1 and 2; Online appendix 1), as well as the detailed clinical information (injury and illness types, locations, aetiology, etc; Online appendices 2-7) for all the sports in the Tokyo 2020 Olympics. Our results can help both team athlete medical staff and event organisers plan and optimise their health care provision, and, more importantly, prevention measures according to the diagnoses and risk profile of their athlete populations. For example, based on these results, a BMX cyclist's need of medical care and prevention measures is different from that of a marathon swimmer, demonstrated by their distinct injury and illness profiles (frequencies, clinical presentations, degrees of severity, etc). Importantly, the International Federations governing the sports presenting high injury and illness incidences, including the sports new on the Olympic programme, must use these data with an aim to reduce the risk in future events.

It is evident that the COVID-19 pandemic and the hot and humid environment each in their own way presented considerable challenges for the athletes, support staff and the overall organisation of the Games. Our results indicate that both factors were substantially mitigated through the comprehensive countermeasures developed for the Games. The success of these mitigation programmes speaks to the potency of all relevant stakeholders (ie, event organisers, governments, scientific experts and organisations, athletes and their entourage) coming together through deliberate collaboration and planning, providing a legacy strategy for future events. However, preventing a problem is better than solving it. While little could have been done to prevent the COVID-19 pandemic, it would be beneficial for the athletes, organising committee, and all other stakeholders if future Summer Olympic Games could be held in cooler environments better suited for intense physical exertion. This will reduce the need for resources to implement exertional heat illness countermeasures (from both event organisers and the athletes) and maximise the athletes' chances to safely reach their peak performance.

Conclusion

In summary, 9% of the athletes were injured and 4% ill during the Tokyo 2020 Summer Olympic Games. While the injury incidence was similar to that of previous Games, the illness incidence was lower. This may largely be attributed to the extensive countermeasures in place to mitigate COVID-19, effectively reducing transmission of not only COVID-19 but all respiratory infections. Heat and humidity posed a challenge to athletes, support teams and organisers, but exertional heat illnesses were mitigated through a host of cooling and hydration strategies. Some of the new sports on the Olympic programme presented high injury incidences. Our results can inform both the planning of future Olympic Games and similar events, the provision of health care to athletes in such events, as well as further research on understanding why the most frequent injuries and illnesses occur, and how to prevent them in the future.

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