Incidence and burden of injury at the Tokyo 2020 Paralympic Games held during the COVID-19 pandemic: a prospective cohort study of 66 045 athlete days

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ABSTRACT

Objective To describe the epidemiology of injuries at the Tokyo 2020 Paralympic Games, including injuries sustained in the new sports of badminton and taekwondo.

Methods Injury data were obtained daily via the established web-based injury and illness surveillance system (WEB-ISS; 81 countries, 3836 athletes) and local organising committee medical facilities (81 countries, 567 athletes). Univariate unadjusted incidences (injuries per 1000 athlete days with 95% CIs), injury proportion (IP, %) and injury burden (days lost per 1000 athlete days) are reported.

Results A total of 4403 athletes (1853 women, 2550 men) from 162 countries were monitored prospectively during the 3-day pre-competition and 12-day competition periods (66 045 athlete days). 386 injuries were reported in 352 athletes (IP=8.0%) with an incidence of 5.8 per 1000 athlete days (95% CI 5.3 to 6.5). Football 5-a-side (17.2), taekwondo (16.0), judo (11.6) and badminton (9.6) had the highest incidence. There was a higher incidence of injuries in the pre-competition period than in the competition period (7.5 vs 5.4; p=0.0053). Acute (sudden onset) injuries and injuries to the shoulder (0.7) and hand/fingers (0.6) were most common. Injury burden was 10.9 (8.6–13.8), with 35% of injuries resulting in time loss from training and competition.

Conclusion Compared with previous Paralympic Games, there was a reduction in injury incidence but higher injury burden at the Tokyo 2020 Paralympic Games. The new sports of taekwondo and badminton had a high injury incidence, with the highest injury burden in taekwondo, compared with other sports. These findings provide epidemiological data to inform injury prevention measures for high-risk sports.

WHAT IS ALREADY KNOWN ON THIS TOPIC
⇒ During the Paralympic Games the incidence of injury has been shown to be high in sports of football 5-a-side, judo and athletics.
⇒ Most common injuries are reported to be acute (sudden onset) in nature, occurring in the shoulder, lower leg, hand and fingers as well as head/face.
⇒ The incidences of injury in the sports of taekwondo and badminton, which were introduced as new sports to the Tokyo 2020 Paralympic Games, have not been reported in previous research.

WHAT THIS STUDY ADDS
⇒ This is the third significant dataset to document injuries in a summer Paralympic Games setting, as well as the first to document injuries sustained during the COVID-19 pandemic.
⇒ There was a lower incidence of injury at the Tokyo Paralympic Games compared with previous Paralympic Games.
⇒ The sports of football 5-a-side, taekwondo, judo and badminton had the highest incidence of injury.
⇒ The new sports of taekwondo and badminton were highlighted as high risk for injury. This was particularly true for taekwondo, where athletes sustained concussions and serious injuries.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY?
⇒ High-risk sports require intervention to reduce injuries to athletes. Prevention practices (eg, rule changes, better preparation for competition, scheduling, recovery practices) and programmes (to address intrinsic risks) are urgently needed.
⇒ These data can help to develop these interventions and measure efficacy.

INTRODUCTION

Injury surveillance studies at the Paralympic Games have been in effect since the Salt Lake City 2002 Paralympic Winter Games. 1 From the London 2012 Games onwards, the Paralympic Injury and Illness Surveillance Study has been used to report the epidemiology of injuries in both Summer and Winter Games settings. 2-4 These studies have shown that the injuries are mostly acute (sudden onset) in nature and most common in high velocity or direct...
A higher incidence of injury has been reported during the 3 days prior to the opening of the Paralympic Games (pre-competition period) compared with the competition period of the Games. Furthermore, the shoulder, lower leg, hand and fingers, as well as head/neck are most at risk for injury. However, most injuries reported were estimated to require no or minimal time loss from training or competition. Longitudinal prospective monitoring studies have also provided much-needed information regarding injuries that occur outside of competition, such as the occurrence of more repetitive (gradual onset) injuries. These studies inform injury prevention interventions, which have been shown to reduce injury incidence, especially in sports that have been identified as high risk. Ongoing Games-time injury surveillance is crucial for continued protection of the health of athletes in environments with multiple sports and teams.

Unlike previous iterations of the Paralympic Games, the Tokyo 2020 Paralympic Games were held under unprecedented circumstances. These Games were hosted in a ‘safety-first’ environment that has been described in The Playbook, which was a set of countermeasures developed prior to the Tokyo Olympic and Paralympic Games held during the COVID-19 pandemic. There were also fewer opportunities for training and meaningful competition during the pandemic months prior to the Games which, in combination with the countermeasures at the Games, may have impacted on sport performance and perhaps injury risk in participating athletes. This study aimed to describe the epidemiology of injury at the Tokyo 2020 Paralympic Games during the global COVID-19 pandemic, and also provides the first epidemiological description of injuries sustained in the new sports of badminton and taekwondo. The findings of this study will contribute to the growing understanding of the epidemiology of injuries in Paralympic sport.

METHODS
This is a prospective cohort study of injuries reported during the 15 days of the Tokyo 2020 Paralympic Games pre-competition (3 days) and competition (12 days) periods in 23 sports, and forms part of an ongoing epidemiological study at the Paralympic Games.

Participants
Members of the International Paralympic Committee (IPC) Medical Committee conducted this study at the Tokyo 2020 Paralympic Games. During the registration process for the Paralympic Games, all athletes consented for the use of medical data gathered during the Games to be used for the current study in a deidentified manner.

Data collection
Information about the study was distributed to all National Paralympic Committee (NPC) Chefs de Missions, as well as to chief medical officers and medical staff of teams prior to the Games. Detailed information about the study was provided at a medical briefing held during the pre-competition period.

The three sources of data for this study were: (1) the IPC master list of competitors at the Games used for athlete information (age groups: 12–25 years, 26–34 years and 35–75 years), sex (female, male), and sport (archery, athletics, badminton, boccia, canoe, cycling (combining track and road), equestrian, football 3-a-side, goalball, judo, powerlifting, rowing, shooting, sitting volleyball, swimming, table tennis, taekwondo, triathlon, wheelchair basketball, wheelchair fencing, wheelchair rugby, wheelchair tennis); (2) the established Web-Based Injury and Illness Surveillance System (WEB-ISS) used by team medical staff to report injuries sustained by athletes in their team; and (3) data obtained from the local organising medical services (polyclinic and sport venue) facilities, primarily used by teams without their own medical support. The polyclinic was also used for specialist medical encounters by teams with medical care. These included clinical visits for radiology services, hospital, specialist medical services, physiotherapy, rehabilitation services and pharmacy encounters. In instances where the same injury was reported through both the polyclinic and the WEB-ISS dataset (identified by accreditation number), each injury was counted only once and was based on the best clinical description in each injury report.

After closure of the Games, both WEB-ISS and polyclinic data were cleaned to remove non-applicable data (non-athletes, duplicate entries). Data related to physiotherapy visits, radiology requests, routine dental treatments, non-ophtalmological eye examinations (optometry), pharmacy visits and bracing requests were excluded. The WEB-ISS and polyclinic data were then de-identified and integrated for analysis, and duplicates between the two systems removed, prior to being merged via accreditation number with the IPC master list for statistical analysis. Thus, the present study comprises all injuries reported by team medical staff and the polyclinic staff during the Tokyo 2020 Paralympic Games.

Definition of injury
The definitions for injuries requiring medical attention were in accordance with the International Olympic Committee (IOC) consensus statement, as well as the Para sport translation of the consensus, regarding injury and illness reporting in sport and are presented in online supplemental file 1. The age, sex, sport, impairment (WEB-ISS entries only) and competition period in which the athlete was injured, as well as the onset (chronicity), anatomical area and estimated time loss of the injury were reported.

Calculation of athlete days
Team sizes were determined by using the master list of participating athletes in each team published by the IPC immediately prior to the Games. An estimate of athlete days was calculated by multiplying the number of athletes in each team by the total participation days (15 days) and for two distinct time periods during the Games: a 3-day pre-competition period and a 12-day competition period. These data comprised denominator data for the calculation of injury incidence (per 1000 athlete days). This is consistent with the previous methodology of these studies.

Calculation of the injury proportion and incidence and incidence ratio
Injury proportion (IP) was calculated as the percentage of athletes who sustained one or more injuries during the Games. The percentage of athletes was calculated as the number of athletes with an injury divided by the total number of athletes competing in the relevant subgroup, multiplied by 100. The estimated number of athlete days was calculated for each sport, age category, sex, competition periods, onset and anatomical areas. The injury incidence was calculated as the number of athletes with an injury relative to the total athletes competing in each category and reported as injuries per 1000 athlete days. Incidence was reported for all
injuries as well as injuries sustained in each of the 23 sports, by sex and age category, by pre-competition and competition period, by onset of injury, and by anatomical area. The incidence ratio (IR) was calculated to show the relative difference between incidences.

Calculation of time loss and burden
Injuries resulting in time loss from training and competition were reported by team medical staff as well as polyclinic staff, with time loss from the injury (days) estimated at the time of injury. The injury burden (IB) was expressed as days lost per 1000 athlete days (95% CI).

Statistical analysis of the data
All data were analysed using SAS statistical software Version 9.4 (Cary, North Carolina, USA) via counts (the number of injuries each doctor reported). Impairment data were only reported as the total number of injuries and percentage of all injuries, because impairment information of all uninjured athletes was not available. Athletes who participated in multiple sports were included under their primary sport. Where athletes sustained more than one injury during the Games, each injury was reported as a separate encounter. Descriptive statistical analyses were reported, including number of athletes participating in 23 sports, by age, sex, pre- and competition periods, chronicity, anatomical area, impairment, number of reported injuries and number and percentage of athletes with an injury. The Poisson distribution with the PROC GENMOD statement and an associated log link option were used for analysis. All results reported were from univariate Poisson models and included a scale parameter, due to some modest overdispersion in the Poisson models. Univariate unadjusted incidences (with 95% CIs) were reported for injury overall, injury by sport, sex and age, by onset, by period and by anatomical area. To determine IR, the ratio between incidences was calculated for significantly different variables. The IB was expressed as days lost per 1000 athlete days (95% CI).

RESULTS
Participants
During this study a total of 4403 athletes (1853 women, 2550 men) from 162 countries were monitored for 15 days (66045 athlete days; table 1). There were 3836 athletes (87% of all athletes) from 81 countries (50% of all countries) that were monitored by team medical staff using the WEB-ISS, as well as 567 athletes from 81 countries that used the local polyclinic medical services. The number of athletes by sex and age category participating in 23 sports (cycling track and road combined) at the Games is shown in table 1.

Overall incidence of injury
A total of 386 injuries (306 WEB-ISS, 80 polyclinic) were reported in 352 athletes (301 WEB-ISS, 51 polyclinic) at the Tokyo Paralympic Games. The IP (%) of all athletes who sustained an injury during the Games was 8%, with an overall incidence of 5.8 injuries per 1000 athlete days (95% CI 5.3 to 6.5). There were more new injuries reported (n=313; 4.7 (95% CI 4.2 to 5.3)) compared with recurrent and subsequent injuries (n=73; 1.1 (95% CI 0.9 to 1.4); IR=4.3 (95% CI 3.3 to 5.6); p<0.0001). There were 342 sport-related injuries in 316 athletes (5.2 (95% CI 4.6 to 5.8)) and 44 non-sport-related injuries in 41 athletes (0.62 (95% CI 0.43 to 0.81); IR=7.8 (95% CI 5.6 to 10.8); p<0.0001). All tables show both sport-related and non-sport-related injuries, except table 6 (anatomical area) which shows only sport-related injuries.

<table>
<thead>
<tr>
<th>Table 1 Number of athletes participating in each of the 23 sports at the Tokyo 2020 Paralympic Games</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sport</td>
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<tr>
<td>---</td>
</tr>
<tr>
<td>All</td>
</tr>
<tr>
<td>Archery</td>
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<tr>
<td>Athletics</td>
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<tr>
<td>Badminton</td>
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<tr>
<td>Boccia</td>
</tr>
<tr>
<td>Canoe</td>
</tr>
<tr>
<td>Cycling (track and road)</td>
</tr>
<tr>
<td>Equestrian</td>
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<tr>
<td>Football 5-a-side</td>
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<tr>
<td>Goalball</td>
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<tr>
<td>Judo</td>
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<tr>
<td>Powerlifting</td>
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<tr>
<td>Rowing</td>
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<tr>
<td>Shooting</td>
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<tr>
<td>Sitting volleyball</td>
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<tr>
<td>Swimming</td>
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<tr>
<td>Table tennis</td>
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<tr>
<td>Taekwondo</td>
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<tr>
<td>Triathlon</td>
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<tr>
<td>Wheelchair basketball</td>
</tr>
<tr>
<td>Wheelchair fencing</td>
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<tr>
<td>Wheelchair rugby</td>
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<tr>
<td>Wheelchair tennis</td>
</tr>
</tbody>
</table>
Incidence of injury by sport

The incidence of all injuries by sport is shown in table 2. The incidence of injury was highest in football 5-a-side (17.2 (95% CI 10.6 to 28.0); IR=3.3 (95% CI 2.0 to 5.5); p<0.0001), taekwondo (16.0 (95% CI 9.9 to 25.7); IR=3.1 (95% CI 1.9 to 5.0); p<0.0001), judo (11.6 (95% CI 7.7 to 17.6); IR=2.2 (95% CI 1.4 to 3.4); p=0.0003) and badminton (9.6 (95% CI 5.6 to 16.6); IR=1.8 (95% CI 1.1 to 3.2); p=0.0311) compared with the incidence of all other injuries.

Incidence of injury by sex and age group

The incidence of injury by sex and age group is shown in table 3. The incidences for men and women are similar. The incidence of injury in athletes aged 26–34 years (6.9 (95% CI 5.9 to 8.1)) was significantly higher than for athletes aged 12–25 years (4.4 (95% CI 3.6 to 5.6)); IR=1.6 (95% CI 1.2 to 2.1); p=0.0014).

Incidence of injury in the 3-day pre-competition and 12-day competition periods

The incidence of injury in the pre-competition and competition periods is shown in table 4. There was a significantly higher incidence of injury during the pre-competition period (99 injuries reported in 95 athletes; 7.5 (95% CI 6.1 to 9.1)) compared with the competition period (287 injuries reported in 269 athletes; 5.4 (95% CI 4.8 to 6.1); IR=1.4 (95% CI 1.1 to 1.7); p=0.0053).

Incidence of injury by onset

The number and incidence of injury by onset is shown in table 5. There was a significantly higher incidence of acute (sudden onset) injuries (3.9 (95% CI 3.4 to 4.4)) compared with repetitive (sudden onset) injuries (1.3 (95% CI 1.0 to 1.6); IR=3.0 (95% CI 2.3 to 3.9); p<0.0001) and repetitive (gradual onset) injuries (0.7 (95% CI 0.5 to 0.9); IR=5.7 (95% CI 4.2 to 7.8); p<0.0001).

Incidence of injury by anatomical area

The anatomical areas affected by sport-related injuries (n=342; 7.7% of all athletes; 6.3 (95% CI 5.6 to 7.0)) are shown in table 6. A total of 44 non-sport-related injuries are not included in this table. For sport-related injuries, the shoulder (n=46; 0.7 (95% CI 0.5 to 0.9)) was the area most affected by injury,
followed by hand and fingers (n=40; 0.6 (95% CI 0.4 to 0.8)), knee (n=31; 0.5 (95% CI 0.3 to 0.7)) and lower leg (n=30; 0.5 (95% CI 0.3 to 0.6)). The details of the nine concussions relating to head/face and neck injuries that were reported at the Tokyo Paralympic Games are shown in online supplemental file 2.

Injury proportion by impairment

The impairment types of 275 athletes with injuries (n=301) whose data were captured on the WEB-ISS are shown in table 7 (polyclinic records did not include impairment information). Of the injured athletes, there were 62 athletes with visual impairment (IP=22.5), 58 athletes with limb deficiency (IP=21.1) and 56 athletes with spinal cord-related disorders (IP=20.4).

Severity of injuries (time loss and injury burden (IB))

Of all injuries reported at the Tokyo Paralympic Games (386 injuries, 133 injuries (34.5%) prevented athletes from training or competition for an estimated period of >1 day (time loss injury) and 253 injuries (65.5%) did not result in time loss. Of the time loss injuries, 87 (65.4%) required 1–3 days exclusion from training or competition. There were 21 (15.8%) injuries that were classified as moderately serious (8–28 days lost) and 10 (7.5%) injuries that were classified as serious (28 days–3 months lost). Half of these injuries required 1 month away from training and half required 6–12 weeks away from training.25 26 Two serious injuries each were recorded for the sports of taekwondo, cycling and sitting volleyball. The most serious injuries included bone fractures, retinal detachment, pneumothorax and knee anterior cruciate ligament rupture.

The overall IB was 10.9 days lost per 1000 athlete days (95% CI 8.6 to 13.8). Although the highest number of total days lost occurred with athletics (195 days lost; IB 11.4 (95% CI 9.8 to 13.1)), the highest number of days lost per 1000 athletes was for taekwondo (IB 78.9 (95% CI 52.1 to 84.1)) followed by football 5-a-side (IB 49.5 (95% CI 36.2 to 66.0)), judo (IB 33.3 (95% CI 25.9 to 42.2)), badminton (IB 21.5 (95% CI 14.4 to 30.9)) and goalball (IB 13.6 (95% CI 8.7 to 20.2)). Athletes in the age group 26–34 years (IB 14.5 (95% CI 10.3 to 20.5)) had a significantly higher IB compared with athletes in the age group of 12–25 years (IB 6.2 (95% CI 3.6 to 10.5); p=0.0081), but not compared with the age group of 35–75 years (IB 10.8 (95% CI 7.1 to 16.4)). There were no significant differences in IB regarding the sex of the athlete (women: IB 11.0 (95% CI 7.7 to 15.7); men: IB 10.9 (95% CI 7.9 to 14.9)).

**DISCUSSION**

The current study comprises the third iteration of the Paralympic Injury and Illness Surveillance Study in the summer setting, following the London and Rio Paralympic Games, and aimed to describe the epidemiology of injuries at the Tokyo 2020 Paralympic Games. The main findings of this study are that: (1) there was a lower incidence of injury compared with previous summer Paralympic Games; (2) the newly introduced Paralympic sports of taekwondo and badminton have a high incidence of injury; (3) there was an increase in severity (IB) of injury compared with previous summer Paralympic Games.

The findings of the current study also support previous findings regarding the incidence and nature of injuries in athletes with disability. Football 5-a-side remains the sport with the highest incidence of injury across three successive Paralympic Games, with judo also highlighted as high risk for injury. Injuries incurred during the Paralympic Games are mostly acute (sudden onset) in nature and occur at a higher incidence in the pre-competition period. Furthermore, the anatomical areas of the shoulder, head/face, hand and fingers as well as certain areas of the lower limb are at risk for injury.

**Lower incidence of injury at the Tokyo 2020 Paralympic Games**

The first important finding of this study was that the incidence of injury at the Tokyo Paralympic Games (incidence 5.8; IP=8%) was considerably lower than previously recorded at the London Games (incidence 12.7; IP=11.6%) and Rio Games (incidence 10.0; IP=12.1%).25 26 Indeed, there was a reduction in injury incidence in nearly all sports, with the exception of goalball, athletics, cycling and rowing. While a lower incidence of illness may have been expected with the COVID-19 countermeasures implemented at these Games, the reasons for the lower incidence of injury are not directly apparent. Over the past decade there have been significant developments in the education and practice of sports physicians which could perhaps translate to

**Table 4** Incidence of injury in the pre-competition and competition periods for athletes competing at the Tokyo 2020 Paralympic Games

<table>
<thead>
<tr>
<th>Period</th>
<th>Total no of injuries (% total no of injuries)</th>
<th>No of athletes with an injury</th>
<th>Total no of athletes competing</th>
<th>Total no of athlete days</th>
<th>Proportion of athletes with an injury (%)</th>
<th>Injury incidence: injuries/1000 athlete days (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>386 (100)</td>
<td>352</td>
<td>4403</td>
<td>66 045</td>
<td>8.0</td>
<td>5.8 (5.3 to 6.5)</td>
</tr>
<tr>
<td>Pre-competition</td>
<td>99 (25.6)</td>
<td>95</td>
<td>4403</td>
<td>13 209</td>
<td>2.2</td>
<td>7.5 (6.1 to 9.1)†</td>
</tr>
<tr>
<td>Competition</td>
<td>287 (74.4)</td>
<td>269</td>
<td>4403</td>
<td>52 836</td>
<td>6.1</td>
<td>5.4 (4.8 to 6.1)†</td>
</tr>
</tbody>
</table>

Some athletes (n=12) sustained more than one injury in the pre-competition period, resulting in total numbers of injuries not equaling the total listed for the entire Games period. *Significantly higher incidence than competition period (p=0.0053).

**Table 5** Incidence of injury by onset (chronicity) for 4403 athletes competing at the Tokyo 2020 Paralympic Games (60 045 athlete days)

<table>
<thead>
<tr>
<th>Type of injury</th>
<th>Total no of injuries (% total no of injuries)</th>
<th>Proportion of athletes with an injury (%)</th>
<th>Injury incidence: injuries/1000 athlete days (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>386 (100)</td>
<td>8.0</td>
<td>5.8 (5.3 to 6.5)</td>
</tr>
<tr>
<td>Acute (sudden onset)</td>
<td>256 (66.3)</td>
<td>5.4</td>
<td>3.9 (3.4 to 4.4)†</td>
</tr>
<tr>
<td>Repetitive (sudden onset)</td>
<td>85 (22.0)</td>
<td>1.9</td>
<td>1.3 (1.0 to 1.6)†</td>
</tr>
<tr>
<td>Repetitive (gradual onset)</td>
<td>45 (11.7)</td>
<td>1.0</td>
<td>0.7 (0.5 to 0.9)†</td>
</tr>
</tbody>
</table>

*Significantly higher incidence than repetitive (sudden onset) and repetitive (gradual onset) injuries (p<0.0001).
†Significantly higher incidence than repetitive (gradual onset) injuries (p=0.0005).
improved medical management and injury prevention strategies over time.\textsuperscript{17} However, it is unknown whether these improvements alone account for the large reduction in injuries seen in one Games cycle, as observed at the Tokyo Paralympic Games.

The alteration of training and competition opportunities prior to the Games, as well as curtailment of social interactions within venues and in external environments at the Games, may have resulted in less exposure to physical stress experienced by the athletes before and during the Games period—that is, with less total exposure to circumstances that may result in an injury, the risk for injury is reduced.\textsuperscript{18} The lack of spectators may have also influenced the psychological load on athletes performing at the Games, perhaps reducing performance anxiety. Whereas exposure to physical load is understood to be an underpinning principle of injury risk,\textsuperscript{18, 19} the psychological load placed on athletes during competition by spectators is relatively under-investigated.\textsuperscript{20}

It may be interesting to speculate on immune function linking illness and increased injury risk.\textsuperscript{21, 22} There is a well-established understanding that injury—specifically traumatic injury—has a negative impact on the functioning of an individual’s immune system.\textsuperscript{19} However, little is known about the effect of illness on

\begin{table}[h]
\begin{center}
\begin{tabular}{|l|c|c|c|c|}
\hline
Anatomical area & Total no of injuries (% total no of sport-related injuries) & No of athletes with an injury & Proportion of athletes with a sport-related injury (%) & Injury incidence: no of injuries/1000 athlete days (95% CI) \\
\hline
All & 342 (100) & 338 & 7.7 & 6.3 (5.6 to 7.0) \\
Shoulder & 46 (13.5) & 46 & 1.0 & 0.7 (0.5 to 0.9) \\
Hand and fingers & 40 (11.7) & 38 & 0.9 & 0.6 (0.4 to 0.8) \\
Knee & 31 (9.1) & 31 & 0.7 & 0.5 (0.3 to 0.7) \\
Lower leg & 30 (8.8) & 30 & 0.7 & 0.5 (0.3 to 0.6) \\
Lumbosacral spine & 26 (7.6) & 26 & 0.6 & 0.4 (0.3 to 0.6) \\
Hip and groin & 23 (6.7) & 23 & 0.5 & 0.3 (0.2 to 0.5) \\
Thigh & 22 (6.4) & 22 & 0.5 & 0.3 (0.2 to 0.5) \\
Elbow & 21 (6.1) & 21 & 0.5 & 0.3 (0.2 to 0.5) \\
Ankle & 21 (6.1) & 21 & 0.5 & 0.3 (0.2 to 0.5) \\
Foot & 16 (4.7) & 15 & 0.3 & 0.2 (0.1 to 0.4) \\
Head and face\textsuperscript{*} & 14 (4.1) & 14 & 0.3 & 0.2 (0.1 to 0.4) \\
Wrist & 14 (4.1) & 13 & 0.3 & 0.2 (0.1 to 0.4) \\
Forearm & 11 (3.2) & 11 & 0.2 & 0.2 (0.1 to 0.3) \\
Neck\textsuperscript{†} & 9 (2.6) & 9 & 0.2 & 0.1 (0.1 to 0.3) \\
Upper arm & 8 (2.3) & 8 & 0.2 & 0.1 (0.1 to 0.2) \\
Chest & 4 (1.2) & 4 & 0.1 & – \\
Thoracic spine & 3 (0.9) & 3 & 0.1 & – \\
Abdominal & 1 (0.3) & 1 & 0.0 & – \\
Non-specific /other & 2 (0.6) & 2 & 0.0 & – \\
\hline
\end{tabular}
\end{center}
\caption{Incidence of 342 sport-related injuries in each anatomical area for athletes competing at the Tokyo 2020 Paralympic games, in descending order of injury incidence}
\end{table}

\begin{table}[h]
\begin{center}
\begin{tabular}{|l|c|c|c|}
\hline
Impairment type & Total no of injuries (% total no of injuries on WEB-ISS) & No of athletes with an injury & Proportion of athletes with an injury on WEB-ISS (%) \\
\hline
All & 301 (100) & 275 & 100 \\
Visual impairment & 67 (22.2) & 62 & 22.5 \\
Limb deficiency (amputation, dysmelia) & 65 (21.6) & 58 & 21.1 \\
Spinal cord-related disorders (eg, paraplegia, tetraplegia) & 62 (20.6) & 56 & 20.4 \\
Brain disorders (eg, cerebral palsy, traumatic brain injury, stroke, multiple sclerosis) & 37 (12.3) & 35 & 12.7 \\
Neuromuscular disorders – stable (eg, post polio syndrome, peripheral nerve injury) & 18 (6.0) & 18 & 6.5 \\
Leg length difference & 13 (4.3) & 12 & 4.4 \\
Intelectual impairment & 11 (3.7) & 10 & 3.6 \\
Neuromuscular disorders – progressive (eg, neuromuscular disease, myopathy; muscular dystrophy) & 9 (3.0) & 6 & 2.2 \\
Short stature & 8 (2.6) & 7 & 2.6 \\
Impaired passive range of motion (eg, arthrogyrosis, clubfoot) & 6 (2.0) & 6 & 2.2 \\
Other / unknown & 5 (1.7) & 5 & 1.8 \\
\hline
\end{tabular}
\end{center}
\caption{Description of the impairment of the 275 athletes with an injury on the WEB-IISS at the Tokyo 2020 Paralympic Games}
\end{table}
cellular function that may disrupt homeostasis and predispose that individual to injury. There was also a considerable reduction in illness observed at the Tokyo Paralympic Games (see the companion paper on the epidemiology of illness at the Tokyo Paralympic Games) which, along with the reduction in injury reported here, indicates a possible complex link between the two. However, further in-depth studies are required to provide mechanisms by which this phenomenon could occur.

New sports of taekwondo and badminton have a high incidence of injury

The second important finding of this study was that the incidence of injury in the newly introduced sports of taekwondo (incidence 16.0; IP 21.1%) and badminton (incidence 9.6; IP 13.3%) ranked second and fourth highest, respectively, with football 5-a-side (incidence 17.2; IP 22.6%) ranked first and judo (incidence 11.0; IP 15.2%) ranked third. There were also two concussions and two serious injuries sustained during taekwondo (see online supplemental file 2). Taekwondo has been shown to be high risk for acute (sudden onset) injury in able-bodied participants, given the nature of the sport with explosive contact between athletes, with a similar proportion of injured taekwondo athletes at the Olympic and Paralympic Games (24–39% Olympic vs 21% Paralympic). This is the first report of injuries sustained by athletes competing in taekwondo and badminton at the Paralympic Games and studies further investigating risks and mitigation strategies are warranted.

Increased severity of injury at the Tokyo 2020 Paralympic Games

It is important to note that, while the injury incidence was reduced at the Tokyo Paralympic Games, it appears that injuries sustained were more severe. The frequency of time loss injuries was higher when compared with previous Games (35% for Tokyo vs 25% for Rio). Furthermore, there were 10 injuries associated with time loss of more than a month away from training or competition. These injuries were mostly observed in cycling, taekwondo and sitting volleyball and included mostly bone fractures. Within sports, taekwondo was ranked first in IB (IB 78.9) followed by football 5-a-side (IB 49.5) and judo (IB 33.3). Taekwondo thus presented with both a high incidence as well as a high IB in the sport’s first Paralympic Games and influenced the overall higher burden observed at these Games. This finding indicates that prevention practices (eg, rule changes, better preparation for competition, scheduling, recovery practices) and programmes (to address intrinsic risks) are urgently needed. It is important to reduce both minor and major injuries in the Paralympic Games setting, and understanding characteristics of major injuries may help medical staff to reduce the likelihood of their occurrence.

Study limitations

This study comprises a significant contribution to the literature. However, the study was potentially limited by the use of team sizes from the IPC master list, where the total team size used may not have represented the true nature of the team size, given the staggered nature of arrival/departure that occurred at the Tokyo Paralympic Games. Determining true team sizes would require each individual athlete to be tracked as they arrived at and left the Village, which was not possible. Thus, using crude team sizes overestimated the true number of athletes in the village at any one time, which affected the calculation of true athlete day exposure denominator data and consequently underestimated the incidence of injury. This difference is represented by approximately 18% more athlete days (10 000) and fewer injuries (1.0) per 1000 athlete days. IPs can be used to directly compare with previous Games, as these did not include athlete day exposure data. In addition, the analyses performed in these studies are univariate, which do not allow for the description of risk factors. A further limitation was the lack of impairment data for all athletes at the Games, limiting the incidence reporting per impairment type (not available for the polyclinic system). Finally, it is important to note that this study reports Games-time injury incidences, which do not reflect injuries sustained outside of competition time.

CONCLUSION

This study is the third report of injuries sustained during the summer Paralympic Games, as well as the first description of injuries sustained by athletes at a Paralympic Games held in an environment in which novel countermeasures were in place to protect the health and safety of athletes. There was a marked reduction in the overall incidence but not in the severity of injuries observed at the Tokyo Paralympic Games compared with previous Games. The lower incidence may have been the result of one or more of the measures related to the COVID-19 pandemic. The high incidence of injury in the new sports of taekwondo and badminton is of concern and warrants development and implementation of prevention strategies in these sports. The findings included in this study contribute to baseline epidemiological data as well as inform injury prevention measures in high-risk sports.

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Competing interests All authors have completed and submitted COI forms. WD is an associate editor of BJSIM IPHP editions.

Patient and public involvement Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval All athletes provided consent for the use of medical data collected during the Paralympic Games to be reported in a de-identified format. Prior to research activities, ethical approval was granted by the Research Ethics Committees of the University of Brighton (FREGS/ES/12/11) and Stellenbosch University (N16/05/067). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available.

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REFERENCES
Supplement 1

Definition of injury
The definition for injuries being reported was ‘tissue damage or other derangement of normal physical function due to participation in sports, resulting from rapid or repetitive transfer of kinetic energy’, and was in accordance with the International Olympic Committee (IOC) consensus statements regarding injury and illness reporting in sport. A new (index) injury was defined as ‘an injury that has never been reported’ on the system before during the Tokyo Games, whereas injuries that were resolved but had recurred were defined as ‘recurrent (same area, same structure)’ and ‘subsequent (same area, different structure)’ injuries. An acute (sudden onset) injury was defined as ‘an injury that is caused by an acute precipitating (sudden onset) event’ – previously termed acute traumatic injury. A repetitive (sudden onset) injury was defined as ‘an acute (sudden onset) injury in an athlete with symptoms of a prior repetitive (gradual onset) injury in the same anatomical area’ – previously termed acute on chronic injury. A repetitive (gradual onset) injury was defined as ‘an injury that developed over days, weeks or months and is not associated with any acute precipitating (sudden onset) event’ – previously termed chronic injury. Injuries are classified by anatomical areas as follows: head/face, neck, cervical spine, shoulder, upper arm, elbow, forearm, wrist, hand/fingers, thoracic spine, chest, abdomen, lumbosacral spine, pelvis/groin, thigh, knee, lower leg, ankle or foot/toes, as well as non-specific injuries.
**Supplement 2:**  
A description of concussion-related injuries reported at the Tokyo 2020 Paralympic Games

<table>
<thead>
<tr>
<th>Reporting of concussion-related injuries</th>
<th>Head/Face</th>
<th>Neck</th>
</tr>
</thead>
<tbody>
<tr>
<td>All injuries to area</td>
<td>16 (incl. 2 non-sport-related)</td>
<td>13 (incl. 4 non-sport-related)</td>
</tr>
<tr>
<td>All concussion-related injuries</td>
<td>6 (38% of head/face injuries; incl. 1 non-sport related)</td>
<td>3 (23% of neck injuries)</td>
</tr>
<tr>
<td>Athlete fulfilled definition of concussion according to consensus statement**</td>
<td>Yes: 5</td>
<td>Yes: 1</td>
</tr>
<tr>
<td></td>
<td>No: 1</td>
<td>No: 2</td>
</tr>
<tr>
<td>Athlete has been concussed before</td>
<td>Yes: 3</td>
<td>Unknown: 3</td>
</tr>
<tr>
<td></td>
<td>No: 1</td>
<td></td>
</tr>
<tr>
<td>SCAT5 was used in assessment</td>
<td>Yes: 2</td>
<td>Unknown: 3</td>
</tr>
<tr>
<td></td>
<td>No: 1</td>
<td></td>
</tr>
<tr>
<td>Decision made to allow athlete to continue sport</td>
<td>Yes: 1</td>
<td>No: 2</td>
</tr>
<tr>
<td></td>
<td>No: 4</td>
<td>Unknown: 1</td>
</tr>
<tr>
<td></td>
<td>Unknown: 1</td>
<td></td>
</tr>
</tbody>
</table>

**Nature of concussions reported**

<table>
<thead>
<tr>
<th>Sport-related / Non-sport-related injuries</th>
<th>Head/Face</th>
<th>Neck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sport-related: Road cycling (2), Judo (1), Swimming (1), Taekwondo (1)</td>
<td></td>
<td>Sport-related: Judo (2), Taekwondo (1)</td>
</tr>
<tr>
<td>Non-sport-related: 1 (pedestrian/vehicle accident in village)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple site injuries</td>
<td>Elbow / forearm: 2</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Foot: 1</td>
<td></td>
</tr>
<tr>
<td>Direct / indirect contact</td>
<td>Direct: 6</td>
<td>Direct: 3</td>
</tr>
<tr>
<td>Athlete impairment</td>
<td>Spinal cord-related disorders: 3</td>
<td>Visual impairment: 2</td>
</tr>
<tr>
<td></td>
<td>Visual impairment: 2</td>
<td>Limb deficiency: 1</td>
</tr>
<tr>
<td></td>
<td>Neuromuscular disorder (stable): 1</td>
<td></td>
</tr>
<tr>
<td>Main presenting symptoms</td>
<td>Headache: 5</td>
<td>Dizziness: 1</td>
</tr>
<tr>
<td></td>
<td>Confusion: 2</td>
<td>Balance: 1</td>
</tr>
<tr>
<td>Difficulty remembering: 1</td>
<td>Unknown: 2</td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>Nausea/vomiting: 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Special investigations

<table>
<thead>
<tr>
<th>MRI scan: 3</th>
<th>MRI scan: 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT scan: 1</td>
<td></td>
</tr>
<tr>
<td>None: 2</td>
<td></td>
</tr>
</tbody>
</table>

### Final diagnosis

<table>
<thead>
<tr>
<th>Concussion: 3</th>
<th>Concussion: 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-concussion syndrome: 1</td>
<td>Concussion secondary to</td>
</tr>
<tr>
<td>Concussion secondary to head</td>
<td>strangulation injury: 1</td>
</tr>
<tr>
<td>laceration/abrasion injury: 2</td>
<td></td>
</tr>
</tbody>
</table>

### Estimated time lost to injury

<table>
<thead>
<tr>
<th>14 days lost: 3</th>
<th>7 days lost: 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 days lost: 1</td>
<td>3 days lost: 1</td>
</tr>
<tr>
<td>3 days lost: 1</td>
<td>No days lost: 1</td>
</tr>
<tr>
<td>No days lost: 1</td>
<td></td>
</tr>
</tbody>
</table>

**Definition of concussion:** Sport related concussion (SRC) may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an impulsive force transmitted to the head. SRC typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, signs and symptoms evolve over a number of minutes to hours. SRC may result in neuropathological changes, but the acute clinical signs and symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies. SRC results in a range of clinical signs and symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive features typically follows a sequential course. However, in some cases symptoms may be prolonged. The clinical signs and symptoms cannot be explained by drug, alcohol, or medication use, other injuries (such as cervical injuries, peripheral vestibular dysfunction, etc) or other comorbidities (eg, psychological factors or coexisting medical conditions).  

**SCAT 5:** Sport Concussion Assessment Tool Version 5.