Incidence of injury and illness at the Beijing 2022 Paralympic Winter Games held in a closed-loop environment: a prospective cohort study of 7332 athlete days

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ABSTRACT

Objective To describe the epidemiology of injuries and illnesses sustained during the Beijing 2022 Paralympic Winter Games, organised in a closed-loop environment to adhere with COVID-19 restrictions.

Methods Injuries and illnesses from all teams were recorded on a daily basis by team medical staff on a web-based form and by local organising committee medical (polyclinic) facilities and venue medical support. Duplicates recorded on both systems were removed. Incidence of injuries and illnesses are reported per 1000 athlete days (95% CI).

Results 564 athletes (426 male and 138 female) representing 46 countries were monitored for the 13-day period of the Beijing 2022 Paralympic Winter Games (7332 athlete days). The overall incidences were 13.0 injuries (10.6–15.8) and 6.1 illnesses (4.5–8.4) per 1000 athlete days. The incidence of injury in alpine skiing (19.9; 15.2–26.1) was significantly higher compared with Nordic skiing, ice hockey and wheelchair curling ($p<0.05$), while the incidence of respiratory illness was significantly higher in Nordic skiing (1.6; 0.9–2.9) compared with alpine skiing, ice hockey and snowboarding ($p<0.05$).

Conclusion The incidence of both injury and illness at the Beijing 2022 Games were the lowest yet reported in the Paralympic Winter Games. The incidence of injury was highest in alpine skiing. These findings underscore the importance of ongoing vigilance and continued injury risk mitigation strategies to safeguard the well-being of athletes in these high-risk competitions. Respiratory illnesses were most commonly reported in Nordic skiing, which included the three cases of COVID-19 recorded at the games.

WHAT IS ALREADY KNOWN ON THIS TOPIC?

⇒ Previous research has shown that incidences of injury and illness are high during Paralympic Winter Games.
⇒ High incidences of injury have particularly been reported among Paralympic athletes participating in alpine skiing and snowboarding.
⇒ Illnesses were most commonly reported in the respiratory, dermatological and ophthalmological systems.

WHAT THIS STUDY ADDS?

⇒ The results showed that 16% and 7% of athletes incurred at least one injury or illness, respectively, during the Beijing 2022 Paralympic Winter Games.
⇒ Overall, incidences of 13.0 injuries (10.6–15.8) and 6.1 illnesses (4.5–8.4) per 1000 athlete days were observed, which were the lowest yet reported among athletes participating at the Paralympic Winter Games.
⇒ Alpine skiing showed the highest incidence and burden of injury.
⇒ Athletes participating in Nordic skiing showed the highest incidence of illness—specifically illnesses in the respiratory system.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY?

⇒ The findings of the current study can guide team physicians and other medical staff as well as organisations of future (inter)national tournaments to protect the health and safety of Paralympic athletes participating in winter sports.
⇒ Longitudinal epidemiological data are imperative for the monitoring and development of injury and illness prevention measures in Paralympic Winter Sports.

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INTRODUCTION

Participating in Paralympic winter sports has been shown to be physically demanding and carries a relatively high risk for injury and illness.[1] Previous iterations of the ongoing Paralympic Injury and Illness Surveillance Studies have shown that the incidence of injuries and illnesses is consistently high during Paralympic Winter Games.[2–5] Alpine skiing, snowboarding and ice hockey were the sports showing the highest incidence of injury, with more than 20 injuries per 1000 athlete days during the Sochi 2014 and PyeongChang 2018 Paralympic Winter Games.[2 4] In addition, overall illness incidences of

more than 10 illnesses per 1000 athletes days across all sports were reported during previous Paralympic Winter Games,[3 5] with the respiratory, dermatological and gastrointestinal systems showing the highest incidences among Paralympic athletes.[3 5–11]

Athletes competing at the Beijing 2022 Paralympic Winter Games, much like the Tokyo 2020 Summer Games, faced unprecedented circumstances during the COVID-19 pandemic. While the Tokyo Games were organised in a bubble format to mitigate the risk of SARS-CoV-2 infection, the Beijing Games were organised within a stricter closed-loop environment, which meant that there was no interaction between people that were inside and outside the Games environment.[12] As opposed to the Tokyo Games, vaccination for COVID-19 was mandatory before travel to the Beijing Games.[13]

Considering the high risks for injury and illness among athletes during Paralympic Winter Games, ongoing robust injury and illness epidemiological data are important to effectively protect the health of Paralympic athletes. Therefore, this study aimed to describe the epidemiology of injuries and illnesses sustained by athletes participating at the Beijing 2022 Paralympic Winter Games.

METHODS

This is a prospective cohort study describing the epidemiology of injuries and illnesses reported during the Beijing 2022 Paralympic Winter Games, which forms part of the ongoing Paralympic Injury and Illness Surveillance Studies.

Participants

Members of the International Paralympic Committee (IPC) Medical Committee conducted this study at the Beijing 2022 Paralympic Winter Games. During the registration process for the Paralympic Games, all participating athletes provided consent for the use of their medical data collected during the Games to be reported in a de-identified format, which was consistent with previous Games settings.

Data collection

Information about the study was distributed to all National Paralympic Committee (NPC) Chefs de mission prior to the Games, as well as to chief team physicians attending the Games. Detailed information about the study was provided at the medical briefing, held during the precompetition period.

The IPC master list of countries and athletes at the Games was used for athlete information, including sport (alpine skiing, ice hockey, Nordic skiing (including cross country skiing and biathlon), snowboard and wheelchair curling), sex (female, male) and age category (12–25 years, 26–34 years and 35–75 years). Team medical staff recorded injuries and illnesses on a web-based form during the precompetition period (ie, 3 days prior to the Games) and the competition period (ie, 10 days of Games time). Data obtained from the local organising committee medical (polyclinic) facilities as well as venue medical support were also included. The polyclinic and venue medical support services were also used for specialist medical encounters by teams with their own medical team. These included clinical visits for radiology services, hospital, specialist medical services, physiotherapy, rehabilitation services and pharmacy encounters.[14] In instances where the same injury or illness was reported by both the team medical staff and polyclinic (including venue medical support), each encounter was only counted once and was based on the best clinical description in each injury or illness report. In case an athlete sustained an injury or illness, their impairment was recorded.

After closure of the Games, records from NPC medical staff and polyclinic data were cleaned to remove non-applicable data (non-athletes). Data related to physiotherapy visits, radiology requests, routine dental treatments, non-ophthalmological eye examinations (optometry) and bracing requests were excluded. Entries were subsequently integrated with the IPC master list and de-identified for statistical analyses, which were performed separately for injuries and illnesses.

Definitions of injury and illness

The definitions for injuries and illnesses being reported are presented in online supplemental file 1. The definitions are in accordance with the International Olympic Committee (IOC) consensus statement regarding injury and illness reporting in sport, as well as the Para sport translation of the consensus.[15 16] The following information was collected per injury and/or illness: Onset of injury/illness, new or subsequent injury/illness, sport-related or non-sport-related injury, anatomical area of injury and physiological system of illness.

Calculation of athlete days, injury proportion and incidence

Team sizes were determined by using the final master list of participating athletes in each team published by the IPC prior to the Games. The calculation of athlete days (total, precompetition and competition periods), injury proportion (IP) and incidence is consistent with the methodology of previous iterations of the Paralympic Injury and Illness Surveillance Studies and presented in supplementary file 2.[2–6 17 18]

Time loss

Injuries and illnesses resulting in time loss from training and competition were reported by team medical staff as well as polyclinic staff. The anticipated time loss (days lost) from training and/or competition was estimated by the medical staff at the time of onset of the injury or illness. The severity of injuries was classified as no time loss (no days lost), minimal (1–7 days lost), moderate (8–28 days lost) or severe (>28 days lost).[16]

Statistical analysis of the data

All data were analysed using SAS statistical software (V.9.4; Cary, North Carolina, USA)/SPSS (V.27) via counts of injuries/illnesses. Impairment data were only reported as the total number of injuries and illnesses and percentage (%) of all injuries or illnesses, because impairment information of all athletes without an injury or illness was not available. Athletes who participated in multiple sports were included under their primary sport. Where athletes sustained more than one injury or illness during the Games, each injury or illness was reported as a separate encounter. Descriptive statistical analyses were reported, including the number of athletes by sport, sex, age category, and precompetition and competition periods, for both injuries and illnesses. Injury counts were also reported by onset, anatomical area and impairment, while illness counts were reported by physiological system and impairment. The Poisson distribution with the PROC GENMOD statement and an associated log link option were used to determine univariate unadjusted

Table 1 Incidence of sport-related injuries in each anatomical area for athletes competing at the Beijing 2022 Paralympic Winter Games, in descending order of incidence

Anatomical area	Total number of sport-related injuries (% total number of sport-related injuries)*	Number of athletes with an injury	Proportion of athletes with an injury (%)	Injury incidence: number of injuries/1000 athlete days (95%CI)
All	**91 (100)**	**86**	**15.2**	**12.4 (10.1 to 15.2)**
Lower limb	29 (31.9)	29	5.1	4.0 (2.8 to 5.6)
Knee	12 (13.2)	12	2.1	1.6 (0.9 to 2.9)
Ankle/foot/toe	4 (4.4)	4	0.7	0.5 (0.2 to 1.4)
Lower leg	6 (6.6)	6	1.1	0.8 (0.4 to 1.8)
Thigh/stump	2 (2.2)	2	0.4	–
Hip/groin/pelvis	5 (5.5)	5	0.9	0.7 (0.3 to 1.6)
Upper limb	26 (28.6)	26	4.6	3.5 (2.4 to 5.2)
Shoulder/upper arm/elbow	18 (19.8)	18	3.2	2.5 (1.6 to 3.9)
Wrist/hand/fingers	8 (8.8)	8	1.4	1.1 (0.5 to 2.2)
Head/face/neck †	17 (18.7)	16	2.8	2.3 (1.4 to 3.8)
Spine	11 (12.1)	11	2.0	1.5 (0.8 to 2.7)
Chest/trunk/abdomen	8 (8.8)	8	1.4	1.1 (0.5 to 2.2)

*Non-sport-related injuries (n=4) are not included in this table, consistent with previous iterations.[2 4]
†Four of these injuries were concussions, as reported by team physicians (alpine skiing: n=2; ice hockey: n=2).

incidences (95% CI). Univariate unadjusted incidences (95% CI) were reported for overall injury and illness, and separately per sport, sex, age category and competition period. To determine incidence ratio (IR), the ratio between incidences was calculated for significantly different incidences between sports, sexes, age categories, precompetition and competition periods and different types of onset, and reported as IR (95% CI). If there were less than four injuries or illnesses recorded in certain subgroups, the incidence for this subgroup was not reported. All tables present both sport-related and non-sport-related injuries, except table 1 (anatomical area) which presents only sport-related injuries, consistent with previous iterations.[2 4]

RESULTS

Participants

There were a total of 564 athletes (426 male (76%) and 138 female (24%)), representing all 46 countries participating at the Games (7332 athletes days). There were 434 athletes from 36 countries (77% of all athletes, 5642 athlete days) who had their own medical support, and 130 athletes from 10 countries (1690 athlete days) who used local polyclinic medical facilities.

The mean (SD) age of all athletes in this study was 31.4 years (9.8 years (range 15–66 years)). Table 2 presents total numbers of athletes, per sport (alpine skiing, ice hockey, Nordic skiing (including cross-country skiing and biathlon), snowboarding, wheelchair curling) and per sex and age category.

Overall incidence of injury and by sport, sex, age category and competition period

A total of 95 (59 team medical staff entries; 36 polyclinic entries) injuries were reported in 89 athletes. The incidence of injury by sport, sex, age category and competition period is shown in table 3. The IP (%) of all athletes who sustained an injury was 16%, with an overall incidence of 13.0 injuries per 1000 athlete days (95% CI 10.6 to 15.8). The incidence of injury was significantly higher in alpine skiing (19.9 (95% CI 15.2 to 26.1)) compared with ice hockey (11.7 (95% CI 7.5 to 18.4); IR=1.7 (95% CI 1.0 to 2.9), p=0.049), Nordic skiing (6.8 (95% CI 4.1 to 11.5); IR=2.9 (95% CI 1.6 to 5.2), p<0.001) and wheelchair curling (5.6 (95% CI 2.2 to 14.4); IR=3.6 (95% CI 1.3 to 9.5), p=0.011). In addition, the incidence of injury was also significantly higher in snowboarding (16.4 (9.4–28.6)) compared with Nordic skiing (6.8 (4.1–11.5); IR=2.4 (95% CI 1.2 to 5.3), p=0.02). There were no significant differences in injury incidence between male and female athletes, neither were there differences in injury incidences between age groups or between precompetition and competition periods (table 3).

Incidence of injury by onset

The number and incidence of injury by onset is presented in table 4. There was a significantly higher incidence of acute (sudden onset) injuries (10.5 (95% CI 8.4 to 13.2)) compared with repetitive (sudden onset) (1.0 (95% CI 0.5 to 2.0); IR=11.0 (95% CI 5.0 to 24.0); p<0.001) and repetitive (gradual onset) injuries (1.5 (95% CI 0.8 to 2.7)); IR=7.0 (95% CI 3.7 to 13.3);

Table 2 Number of athletes (% per category) participating in each of the five sports at the Beijing 2022 Paralympic Winter Games

Sport	All athletes	Female	Male	Age 12–25 years	Age 26–34 years	Age 35–75 years
All	**564**	**138 (24.5)**	**426 (75.5)**	**212 (37.6)**	**174 (30.8)**	**178 (31.6)**
Alpine skiing	170 (30.1)	53 (38.4)	117 (27.5)	79 (37.3)	55 (31.6)	36 (20.2)
Ice hockey	118 (20.9)	1 (0.7)	117 (27.5)	43 (20.3)	28 (16.1)	47 (26.4)
Nordic skiing*	146 (25.9)	52 (37.7)	94 (22.1)	64 (30.2)	57 (32.8)	25 (14.0)
Snowboarding	75 (13.3)	14 (10.1)	61 (14.3)	25 (11.8)	28 (16.1)	22 (12.4)
Wheelchair curling	55 (9.8)	18 (13.1)	37 (8.6)	1 (0.4)	6 (3.4)	48 (27.0)

*Including cross-country skiing and biathlon.

Table 3 Incidence of injury by sport, sex, age and competition period for athletes competing at the Beijing 2022 Paralympic Winter Games

	Total number of athletes competing	Total number of athlete days	Total number of injuries	Number of athletes with an injury	Proportion of athletes with an injury (%)	Injury incidence: number of injuries/1000 athlete days (95%CI)
All	**564**	**7 332**	**95**	**89**	**15.8**	**13.0 (10.6 to 15.8)**
Sport						
Alpine skiing	170	2 210	44	42	24.7	19.9 (15.2 to 26.1)*
Snowboarding	75	975	16	13	17.3	16.4 (9.4 to 28.6)†
Ice hockey	118	1 534	18	17	14.4	11.7 (7.5 to 18.4)
Nordic skiing	146	1 898	13	13	8.9	6.8 (4.1 to 11.5)
Wheelchair curling	55	715	4	4	7.3	5.6 (2.2 to 14.4)
Sex						
Male	426	5 538	65	61	14.3	11.7 (9.2 to 15.0)
Female	138	1 794	30	28	20.3	16.7 (11.9 to 23.6)
Age group						
Age 12–25 years	212	2 756	41	38	17.9	14.9 (11.0 to 20.1)
Age 26–34 years	174	2 262	26	26	14.9	11.5 (8.1 to 16.4)
Age 35–75 years	178	2 314	28	25	14.0	12.1 (8.2 to 17.9)
Precompetition/competition period						
Precompetition	564	1 692	19	19	3.4	11.2 (7.2 to 17.5)
Competition	564	5 640	76	72	12.8	13.5 (10.8 to 16.8)

*Significantly higher than ice hockey (p=0.049), Nordic skiing (p<0.001) and wheelchair curling (p=0.011).
†Significantly higher than Nordic skiing (p=0.02).

p<0.001). In addition, there were more new injuries (12.5 (95% CI 10.2 to 15.4) than subsequent injuries (0.4 (95% CI 0.1 to 1.3); IR=30.7 (95% CI 9.7 to 97.1); p<0.001) and more sport-related injuries (n=91; 12.4 (95% CI 10.1 to 15.2)) than non-sport-related injuries (n=4; 0.5 (95% CI 0.2 to 1.4)); IR=22.8 (95% CI 8.3 to 62.1); p<0.001).

Incidence of injury by anatomical area and time loss

The anatomical areas affected by sport-related injuries (n=91) are presented in table 1. Similar incidences of injury were found for the lower limb (4.0 (95% CI 2.8 to 5.6)) and upper limb (3.5 (95% CI 2.4 to 5.2)). The shoulder/upper arm/elbow complex had the highest incidence of injury (2.5 (95% CI 1.6 to 3.9)), followed by the head/neck/face complex (2.3 (95% CI 1.4 to 3.8)). The number of injuries to the head/neck/face complex were highest in alpine skiing (n=10; 59%). Four concussions were reported, in ice hockey (n=2) and alpine skiing (n=2), with minimal time loss (no days lost: n=2; 1 day lost: n=2). All concussions resulted from (direct) contact.

Estimated time loss was recorded for 80 (87.9%) injuries. Of these injuries, 28 injuries (33.8%) were expected to lead to days lost from training and/or competition for >1 day, while 52 (66.2%) injuries did not lead to time loss. Of the time loss injuries, 11 (39.2%) were classified as severe (>28 days lost). All severe injuries were reported in alpine skiing and included fractures (n=2; clavicular and humeral fracture), anterior cruciate ligament (ACL) injuries (n=2), meniscal tear (n=1), thigh muscle (adductor and quadriceps) tears (n=2), as well as hip contusion (n=1), gastrocnemius strain (n=1), tibial bone bruise (n=1) and humero-ulnar impingement syndrome (n=1).

Injury by impairment

The injuries by impairment are presented in online supplemental file 3. There were 43 injuries (47.3%) recorded in

Table 4 Incidence of injury by onset for athletes competing at the Beijing 2022 Paralympic Winter Games

Type of injury	Total number of injuries	Number of athletes with an injury	Percentage of athletes with an injury	Injury incidence rate: injuries/1000 athlete days (95% CI)
Onset				
Acute (sudden onset)	77	71	12.6	10.5 (8.4 to 13.2)*
Repetitive (sudden onset)	7	7	1.2	1.0 (0.5 to 2.0)
Repetitive (gradual onset)	11	11	2.0	1.5 (0.8 to 2.7)
New or subsequent injuries				
New injuries	91	85	15.1	12.5 (10.2 to 15.4)†
Subsequent injuries	4	4	0.7	0.4 (0.1 to 1.3)
Sport and non-sport-related injuries				
Sport-related injuries	91	85	15.1	12.4 (10.1 to 15.2)‡
Non-sport-related injuries	4	4	0.7	0.5 (0.2 to 1.4)

*Significantly higher than other onsets (p<0.001).
†Significantly higher than subsequent injuries (p<0.001).
‡Significantly higher than subsequent injuries (p<0.001).

Table 5 Incidence of illness by sport, sex, age and competition period for athletes competing at the Beijing 2022 Paralympic Winter Games

	Total number of athletes competing	Total number of athlete days	Total number of illnesses	Number of athletes with an illness	Proportion of athletes with an illness (%)	Illness incidence: number of illnesses/1000 athlete days (95% CI)
All	**564**	**7 332**	**45**	**41**	**7.3**	**6.1 (4.5 to 8.4)**
Sport						
Nordic skiing	146	1 898	26	23	15.8	13.7 (9.1 to 20.6)*
Wheelchair curling	55	715	6	5	9.1	8.4 (3.5 to 20.3)
Alpine skiing	170	2 210	7	7	4.1	3.2 (1.5 to 6.5)
Snowboarding	75	975	3	3	4.0	3.1 (1.0 to 9.3)
Ice hockey	118	1 534	3	3	2.5	2.0 (0.6 to 6.0)
Sex						
Male	426	5 538	31	28	6.6	5.6 (3.8 to 8.2)
Female	138	1 794	14	13	9.4	7.8 (4.6 to 13.3)
Age group						
Age 12–25 years	212	2 756	14	14	6.6	5.1 (3.1 to 8.4)
Age 26–34 years	174	2 262	20	17	9.8	8.8 (5.4 to 14.5)
Age 35–75 years	178	2 314	11	10	5.6	4.8 (2.5 to 8.9)
Competition period						
Precompetition	564	1 692	13	13	2.3	7.7 (4.5 to 13.1)
Competition	564	5 640	32	31	5.5	5.7 (4.0 to 8.0)

*Significantly higher than alpine skiing (p<0.001), snowboarding (p=0.013) and ice hockey (p=0.001).

athletes with limb deficiency, followed by 17 injuries (18.7%) recorded in athletes with spinal cord injury and 15 injuries (16.5%) recorded in athletes with visual impairment.

Overall incidence of illness and by sport, sex, age category and competition period

A total of 45 (31 illnesses reported by team medical staff; 14 polyclinic) illnesses were reported in 41 athletes at the Beijing Games, resulting in an illness proportion of 7.3% of all athletes and an overall incidence of 6.1 illnesses per 1000 athlete days (95% CI 4.5 to 8.4) (table 5).

The sport of Nordic skiing showed the highest incidence of illness (13.7 (95% CI 9.1 to 20.6)), which was significantly higher than ice hockey (IR=7.0 (95% CI 2.1 to 23.0); p=0.001), alpine skiing (IR=4.3 (95% CI 1.9 to 9.9); p<0.001) and snowboarding (IR=4.5 (95% CI 1.4 to 14.5); p=0.01). There were no significant differences in illness incidence between male and female athletes, neither were there differences in illness incidences between age groups or between precompetition and competition periods. There were more new illnesses (n=33; 4.5 (95% CI 3.2 to 6.4)) compared with subsequent illnesses (n=12; 1.6 (95% CI 0.8 to 3.3); IR=2.8 (95% CI 1.3 to 6.0); p<0.01).

Incidence of illness by physiological system and time loss

Table 6 presents the number and incidence of illnesses by physiological system. The respiratory (1.6 (95% CI 0.9 to 2.9)), gastrointestinal (1.4 (95% CI 0.7 to 2.5)) and dermatological (0.8 (95% CI 0.4 to 1.8)) systems had the highest incidence of illness. Combined, these three systems represent 62% of all illnesses. There were three respiratory illnesses diagnosed as COVID-19. All three of these cases were observed in the sport of Para Nordic skiing (biathlon), and two of these cases were from one country.

There were 10 illnesses that required one or more days of absence from training and/or competition (22.2%), while 28

Table 6 Incidence of illness in each primary physiological system for athletes competing at the Beijing 2022 Paralympic Winter Games, in descending order of incidence

Physiological system	Total number of illnesses (% total number of illnesses)	Number of athletes with an illness	Proportion of athletes with an illness (%)	Illness incidence: number of illnesses/1000 athlete days (95% CI)
All	**45 (100)**	**41**	**7.3**	**6.1 (4.5 to 8.4)**
Respiratory	12 (26.6)	12	2.1	1.6 (0.9 to 2.9)
COVID-19	*3 (6.7)*	*3*	*0.5*	–
Gastrointestinal	10 (22.2)	10	1.8	1.4 (0.7 to 2.5)
Dermatological	6 (13.3)	6	1.1	0.8 (0.4 to 1.8)
Genitourinary	5 (11.1)	5	0.9	0.7 (0.3 to 1.6)
Psychiatric/psychological	4 (8.8)	4	0.7	0.5 (0.2 to 1.4)
Neurological	3 (6.7)	2	0.4	–
Ophthalmological	2 (4.4)	2	0.2	–
Thermoregulatory	1 (2.2)	1	0.2	–
Musculoskeletal	1 (2.2)	1	0.2	–
Cardiovascular and circulatory	1 (2.2)	1	0.2	–
Endocrinological, nutritional or metabolic	0	0	0	–
Multiple systems	0	0	0	–
Otological	0	0	0	–

illnesses did not result in time loss (62.2%; time loss unknown: n=7; 15.6%).

Illness by impairment

Illnesses by impairment are presented in online supplemental file 3. Most of the athletes who sustained an illness were athletes with a limb deficiency (n=17; 41.5%), followed by athletes with spinal cord related disorders (n=13; 31.7%), neurological disorders (stable, n=5; 12.2%) and visual impairment (n=3; 7.3%).

DISCUSSION

The current study represents the third iteration of the Paralympic Injury and Illness Surveillance Study in the winter setting.[2–5] The Beijing 2022 Paralympic Winter Games were the second Paralympic Games to be held in a 'safety-first' environment, after the Tokyo 2020 Paralympic Games, in which strict countermeasures were put in place to protect the health of all Games participants and reduce the risk of COVID-19 infection. The main findings of this study were that: (1) The incidence of injury and illness were the lowest yet reported during the Paralympic Winter Games, (2) The incidence of injury was significantly higher in alpine skiing compared with Nordic skiing, ice hockey and wheelchair curling, and (3) The incidence of illness was highest in athletes participating in Nordic skiing (including cross-country skiing and biathlon).

Low overall injury incidence but highest in alpine skiing compared with other sports

The first important finding of this study was that the incidence of injury (13.1 (95% CI 10.5 to 15.7)) was found to be the lowest yet reported during Paralympic Winter Games (Sochi 2014: 26.5 (95% CI 22.7 to 30.8); PyeongChang 2018: 20.9 (95% CI 17.4 to 25.0)).[2 4] The incidence of injury in alpine skiing, however, was significantly higher (19.9 (95% CI 14.0 to 25.8)) compared with ice hockey (11.7 (95% CI 7.5 to 18.4)), Nordic skiing (6.8 (95% CI 4.1 to 11.5)) and wheelchair curling (5.6 (95% CI 2.2 0 14.4)).

Alpine skiing

The high incidence of injury in alpine skiing was consistent with previous Paralympic Winter Games (Sochi 2014: 41.1 (95% CI 33.7 to 49.6); PyeongChang 2018: 23.1 (95% CI 16.5 to 32.1)).[2 4] In addition, all severe injuries (n=11; >28 days lost) were reported in alpine skiing, which mostly included fractures, muscle tears and ACL injuries. The finding of a high injury incidence in alpine skiing over multiple Paralympic Winter Games has led to mitigation strategies being employed, including an increase in provision of training runs, avoidance of steep gradients and widened course designs.[19] The high incidence of injury in alpine skiing shows that continuous evaluation, with subsequent education and implementation of risk mitigation strategies in this sport are important in this sport. High speeds, steep and narrow courses with tight turns as well as warm temperatures have previously been identified as risk factors for injury in alpine skiing.[19] Similar to the Sochi Games, warm temperatures were measured during the Beijing Games (Yanqing alpine skiing centre: 9–19°C; Zhangjiakou snowboarding: 7–19°C).[20] These warm temperatures have been shown to be detrimental for snow conditions, which particularly impacts alpine ski races and could contribute to higher risks for injury. It is important to note that the Paralympic Winter Games are organised approximately 2 weeks after the Olympic Winter Games, which increases the probability of warmer temperatures as the seasons change. In general, the incidence of injury reported among Paralympic athletes with underlying impairments, and sometimes multiple comorbidities, has been shown to be twice as high compared with athletes without disabilities.[21] Warmer temperatures may therefore put Paralympic athletes at even higher risk of injury.

Snowboarding

The incidence of injury reported among athletes who participated in snowboarding during the Beijing Games was second highest (16.4 (95% CI 9.4 to 28.6)). While the incidence of injury in alpine skiing seems to remain high, the incidence of injury in snowboarding was substantially lower compared with previous Paralympic Winter Games (PyeongChang 2018: 40.5 (95% CI 28.5 to 57.7)).[4] This reduction could be due to the improved awareness of high incidence of injuries in this relatively new Paralympic sport, as well as differences in course profile and improvements in equipment following previous Paralympic Winter Games.[2 4]

Concussion

A notable observation pertains to the minimal or no time loss reported after concussions that occurred during the Beijing Games. Four cases of concussion were documented, which occurred during alpine skiing (n=2) and ice hockey (n=2). As has been stated in the latest IOC consensus statement regarding the management and care of sport-related concussion, an athlete has to be removed from their sporting activity and follow a graded return to play protocol before returning to unrestricted activity.[22] In accordance with the definition of concussion published in this IOC consensus statement, symptoms and signs indicative of sport-related concussions can present immediately on impact to the head or neck, or alternatively, they can evolve over a span of minutes to hours. These symptoms, as typically observed, can resolve within days, or may be prolonged. This underscores the importance of immediate removal from athlete's activity and allowing for adequate recovery period following sport-related concussions prior to Paralympic athletes' return to their sport in training and/or competition. Given the professional athlete environment that characterises the Paralympic Games, it is imperative that these sport-related concussions are managed appropriately. The findings of this study underscore the importance of healthcare provider education, particularly with respect to sport-related concussions in Para athletes, which does not differ from the management and care in able-bodied athletes. In a recently published editorial, Runciman *et al* (2022) raised concerns about the potential under-reporting of sport-related concussions in Para athletes. The authors therefore advocate for consistent and accurate documentation of concussive incidents in Para sport and appropriate time loss.[23]

Low illness incidence but higher among athletes participating in Nordic skiing

The incidence of illness (6.1 (95% CI 4.3 to 7.9)) was also found to be the lowest yet reported during Paralympic Winter Games (Sochi 2014: 18.7 (95% CI 15.1 to 23.2); PyeongChang 2018: 12.8 (95% CI 10.2 to 16.0)).[3 5] In addition, although the highest illness incidence was found in the respiratory system (1.6 (95% CI 0.9 to 2.9)), this incidence was lower than reported in previous iterations (Sochi 2014: 5.6 (95% CI 3.8 to 8.0); PyeongChang 2018: 4.1 (95% CI 2.9 to 5.9)).[3 5] This low incidence can likely be explained by effect of the strict COVID-19 countermeasures that were implemented during the Beijing Games, including, but not limited to, minimal physical interaction, wearing of face

masks, regularly washing of hands and use of hand sanitiser.[13] Although these countermeasures were specifically implemented to limit the spread of COVID-19, incidences in all other physiological systems were also reported to be low, for example, in the gastrointestinal and genitourinary systems. The proportion of illnesses that led to time loss from training and competition (22.2%) was, however, consistent with previous Games (Sochi: 21.0%; PyeongChang: 27.7%).[3 5]

Interestingly, it was the first time during Paralympic Winter Games that the incidence of illness in Nordic skiing events (13.7 (95% CI 8.4 to 19.0)) was higher than in other sports, such as alpine skiing, snowboarding and ice hockey. During the Sochi Games, the highest incidence of illness was observed in wheelchair curling (20 (95% CI 10.1 to 39.6), followed by alpine skiing (19.4 (95% CI 13.9 to 27.0)) and ice hockey (19.4 (95% CI 12.6 *t*o 29.9)), while in PyeongChang the highest incidence was observed in snowboarding (19.7 (95% CI 12.0 to 32.2)). Not surprisingly, the most commonly affected physiological system in Nordic skiing during the Beijing Games was the respiratory system (n=10; 40%), which is consistent with previous findings of the Olympic Winter Games.[8 9] Importantly, half of the respiratory illnesses in Nordic skiing were reported as exercise-induced bronchoconstriction (n=5). This has also been recognised as a potential respiratory complication in Olympic athletes,[24 25] which could be caused by high ventilatory requirements as well as dry and cold air.[24] Further investigations are needed to identify impairment-related risk factors.

Limitations

Although injuries and illnesses of the majority of the athletes were recorded by team physicians, information from 23% of the athletes was recorded via polyclinic services. Because of the strict COVID-19 regulations implemented during the Beijing Games and the ongoing potential threat of infection, it is possible that less athletes sought treatment at the polyclinic services. This could have led to an underestimation of the incidence of (minor) injuries and illnesses in this study. In addition, traditionally, a low number of injuries and illnesses has been reported during the Paralympic Winter Games, which limits the methods to an univariate analysis. To draw firm conclusions, more detailed analyses with, for example, merged data sets from multiple Paralympic Winter Games, are needed. Time-loss data were not reported for all medical encounters recorded by the polyclinical services, causing a high percentage of missing severity data for injuries and illnesses. In addition, the analyses included in this study included injuries and illnesses for which athletes sought medical attention only. Furthermore, the number of athlete days (denominator) was estimated based on the number of athletes in each team, which could have led to an overestimation of athlete days. Lastly, the Paralympic Games serve as a short representation of the time that Para athletes dedicate to training and competition. Hence, one needs to take caution in implementing the outcomes of this study or extrapolating findings to individual sports within both the competitive season and off-season contexts. Hence, future studies are needed to investigate the incidence of injury and illness during training and competition periods.

Conclusion

The results of the current study showed that the incidence of injuries and illnesses during the Beijing 2022 Paralympic Winter Games were the lowest yet reported in the Paralympic Winter Games setting. The highest incidence of injury was reported in alpine skiing, which indicates that current implementation of risk mitigating strategies need to continue to ensure safety of Paralympic athletes participating in future alpine skiing events. The low incidence of illness may be explained by the implementation of strict COVID-19 countermeasures, which could have had an effect on the incidence of non-respiratory illnesses as well. These countermeasures may influence athletes' illness prevention strategies going forward in future Games. Future research is needed to identify risk factors relating to athlete's underlying impairments who are participating in these sports.

Equity, diversity and inclusion statement

This study was conducted exclusively in athletes with disability, who are classified as a marginalised group, and was inclusive of all athletes participating at the Beijing 2022 Paralympic Winter Games. The author team is balanced. The researchers represent different genders, from both Northern and Southern hemispheres and different socioeconomic status countries. Furthermore, the research group includes individuals from marginalised groups, as well as perspectives from multiple disciplines.

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