Sports injuries and illnesses in the Sochi 2014 Winter Olympic Games

Torbjørn Soligard,[1] Kathrin Steffen,[2] Debbie Palmer-Green,[3] Mark Aubry,[4] Willem Meeuwisse,[5] Margo Mountjoy,[6] Alexey Pleskov, [7] Kamila Sagitova,[7] Natalia Salmina,[7] Richard Budgett,[1] Lars Engebretsen,[1,2,8]

[1] Medical & Scientific Department, International Olympic Committee, Lausanne, Switzerland

[2] Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway

[3] Division of Orthopaedic & Accident Surgery, Nottingham University Hospital, Nottingham, UK

[4] International Ice Hockey Federation (IIHF), Zurich, Switzerland

[5] Sport Injury Prevention Research Centre, Faculty of Kinesiology, University of Calgary, Alberta, Canada

[6] Fédération International de Natation (FINA), Lausanne, Switzerland

[7] Sochi 2014 Olympic and Paralympic Organizing Committee

[8] Department of Orthopaedic Surgery, University of Oslo, Oslo, Norway

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Correspondence to: Torbjørn Soligard, Medical & Scientific Department, International Olympic Committee, Château de Vidy, 1007 Lausanne, Switzerland; torbjorn.soligard@olympic.org

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Abstract

Background: The Olympic Movement Medical Code encourages all stakeholders to ensure that sport is practised with minimal health risks for the athletes. Systematic surveillance of injuries and illnesses is the foundation for developing preventive measures in sport.

Aim: To analyse the injuries and illnesses that occurred during the XXII Olympic Winter Games, held in Sochi in 2014.

Methods: We recorded the daily occurrence (or non-occurrence) of 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 Sochi Local Organising Committee for the 2014 Olympic Winter Games' (Sochi 2014 LOCOG) medical staff.

Results: In total, 2780 athletes (1121 women (40%), 1659 men (60%) from 88 NOCs participated in the study. NOC and LOCOG medical staff reported 391 injuries and 249 illnesses, equalling incidences of 14.0 injuries and 8.9 illnesses per 100 athletes over a X day period of time. Altogether, 12% and 8% of the athletes incurred at least one injury or illness, respectively. The risk of an athlete being injured was highest in aerial skiing, slopestyle snowboard, snowboard cross, slopestyle skiing, halfpipe skiing, moguls skiing, alpine skiing, and snowboard halfpipe, and lowest in Nordic combined, speed skating, biathlon, ski jumping, cross-country skiing, luge, and short track. Thirty-nine per cent of the injuries were expected to prevent the athlete from participating in competition or training. Females suffered 50% more illnesses than males (10.9 versus 7.3 illnesses per 100 athletes). The rate of illness was highest in skeleton, short track, curling, cross-country skiing, figure skating, bobsleigh and aerial skiing. A total of 159 illnesses (64%) affected the respiratory system and the most common cause of illness was infection (n=145, 58%).

Conclusion: At least 12% of the athletes incurred an injury during the games, and 8% of the athletes an illness, which is similar to prior Olympic Games. The incidence of injuries and illnesses varied substantially between sports.

Introduction

It is well-established that regular exercise provides a number of significant health benefits, including a reduction in the risk of premature death, as well as non-communicable diseases, such as cardiovascular disease, hypertension, some cancers, obesity, and diabetes.[1, 2] Increasing the exercise loads and entering the realm of elite sports does not seem to diminish these beneficial health effects. The majority of the available data suggest that, compared with age-adjusted controls from the general population, elite athletes benefit from a better life expectancy, lower rates of various diseases, as well as lower hospital admission rates.[3-7] However, at the same time, elite athletes are exposed to a high risk of musculoskeletal disorders and long-term disability following their sports participation.[5, 8-11]. In addition, recent studies have documented that athletes' risk of sports-related illnesses is almost equally as high[12-15]

Systematic monitoring of injury and illness trends over long periods of time provides epidemiologic data that are invaluable to protect the health of the athletes – one of the main priorities of the International Olympic Committee (IOC).[16] A scientific, evidence-based understanding of incidence rates, characteristics, risk factors and associated mechanisms of injuries and illnesses, across different sports and athlete populations, provides the opportunity not only to enhance the treatment given to the injured or ill athlete, but more importantly, to inform the development and assessment of prevention measures.

Few International Sports Federations have instituted regular injury and illness surveillance systems in their World Championships and other main events. However, those that have conducted surveillance have done it well, and published their results widely.[14, 15, 17-49] For the 2008 Olympic Games in Beijing, for the first time the IOC convened a group of experts to develop an injury surveillance system for multi-sports events,[50, 51] and in the Vancouver 2010 Olympics the surveillance was expanded to also include illnesses, to account for all health aspects of the elite athlete.[12] The extended approach became the standard and was repeated with success in the London 2012 Olympic Games.[13]

The aim of the present paper is to analyse and describe the injury and illness rates and characteristics in the Sochi 2014 Olympic Games. Practical implications and suggestions for further initiatives and research to protect the athletes´ health are provided.

Methods

We employed the IOC injury and illness surveillance system for multi-sport events in this prospective cohort study.[50] We asked all National Olympic Committee (NOC) medical teams to report the daily occurrence (or non-occurrence) of injuries and illnesses on a standardised medical report form. Concurrently, we retrieved the same information on all athletes treated for injuries and illnesses in the polyclinic and all other medical venues by the Sochi Local Organising Committee for the 2014 Olympic Winter Games' (Sochi 2014 LOCOG) medical staff.

We used the athlete accreditation number to control for duplicates resulting from athletes being treated for the same condition by both the NOC and the Sochi 2014 medical staff. In cases of duplicates, we retained the NOC data.

Implementation

We informed the NOCs about the study in a letter sent four months in advance of the Olympic Games. The day before the opening of the Games we organised a meeting with all NOC medical staff to account for and discuss the study procedures. In this meeting we also started the distribution of the daily injury and illness report forms, as well as an instructional booklet detailing the study protocol.

Throughout the data collection, we recorded the response rate of NOCs having more than 10 participating athletes, and frequently visited these to address any questions and encourage continuous reporting during the games.

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) musculoskeletal complaints or concussions (injuries) or illnesses incurred in competition or training during the Sochi Olympic Games (6 – 23 February 2014) receiving medical attention, regardless of the consequences with respect to absence from competition or training.[50] In cases where a single incident caused multiple injury types or affected multiple body parts, we recorded only the most severe diagnoses.[13]

Injury and illness report form

Our injury and illness record form was identical to the one we used in the 2010 and 2012 Olympic Games.[12, 13] With respect to injuries, we recorded the following information:

accreditation number, 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. Likewise, we recorded the following information for illnesses: accreditation number, sport and event, date, diagnosis, affected system, main symptom(s), cause and estimated time loss.

We provided instructions on how to complete the form correctly in the instructional booklet. Furthermore, we distributed the injury and illness report forms to all NOCs in the following languages: English, French, Chinese, German, Japanese, Russian, and Spanish.

Confidentiality and ethical approval

We recorded and utilised the athlete accreditation number to prevent duplicate records, as well as to query the IOC athlete database for their age, gender and nationality. We treated all information with strict confidence, and anonymised our medical database at the end of the Games.

The study was approved by the medical research ethics committee of the South-Eastern Norway Regional Health Authority.

Data analysis

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 athletes; with incidence values presented as injuries/illnesses per 100 athletes. 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. 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, 2780 athletes took part in the Sochi Olympic Games. Of these, 1121 were women (40%) and 1659 men (60%). There were 8 double-starters, meaning athletes who participated in two different sports or events, giving a total of 2788 athletes exposed to injury or illness.

Incidence and distribution of injuries

Among these athletes, we recorded a total of 391 injuries, equalling an overall injury rate of 14.0 injuries [95% CI: 12.6-15.4] per 100 participating athletes (Table 1). On average, 12% (n=330) of the athletes sustained at least one injury. In addition and there were 43 with two, two with three, and one athlete with four injuries each, respectively.

The rate of injury was highest in aerial skiing (48.8 injuries [95% CI 27.9-69.7] per 100 athletes), slopestyle snowboard (37.0 [19.4-54.5]), snowboard cross (34.4 [19.7-49.2]), slopestyle skiing (30.8 [15.7-45.8]), halfpipe skiing (25.5 [11.6-39.3]), moguls skiing (24.6 [11.7-37.4]), alpine skiing (20.7 [15.7-25.7]), and snowboard halfpipe (18.2 [7.9-28.5]). The injury rates were lowest in Nordic combined, speed skating, biathlon, ski jumping, cross-country skiing, luge, and short track (incidence rates ranging from 4 to 9 injuries per 100 athletes).

The injury rates in female (14.9 injuries [95% CI: 12.7-17.2] per 100 athletes) and male (13.2 [11.4-14.9], RR=1.13 [0.93-1.38], P=0.23) athletes were similar (Table 2). However, female athletes were at significantly higher risk of injury in slopestyle skiing (RR=3.00 [1.04-8.63], P=0.042), whereas male were at higher risk of injury in ski jumping (7 vs. 0 injuries, P<0.001).

Severity, location and type of injuries

While two thirds of the injuries were estimated to not result in any time loss from sport (n=240, 61%), 39% of the injuries (n=151) were expected to prevent the athlete from participating in competition or training. It was estimated that 18% of the injuries (n=69) would result in an absence from sports from 1 to 3 days, 5% (n=21) in an absence from 4 to 7 days, 6% (n=22) in an absence from 8 to 28 days, and 10% (n=39) in an absence for more than 28 days. Information on severity was missing on one injury.

A total of 82 injuries (21%) were classified as severe and entailed an estimated absence from training or competition of more than one week (Table 1). These injuries were

- 27 ligament sprains/ruptures, of which 23 affected the knee (five in moguls, four in alpine skiing, four in ice hockey, three in aerial skiing, three in ski cross, two in snowboard cross, and one each in slopestyle snowboard, ski jumping, and skeleton),
- 15 fractures (three fractures to the foot, hand and finger in ice hockey, three clavicle, forearm, and wrist fractures in alpine skiing, two ankle and face fractures in slopestyle skiing, two fractures to the pelvis and wrist in snowboard cross, two clavicle and elbow fractures in Nordic combined, one elbow fracture in snowboard slalom, one rib fracture in ski cross, and one rib fracture in ski jumping),
- 12 contusions, haematomas or bruises (the majority in snowboard and freestyle skiing),
- six muscle strains (three in ice hockey to the groin, lower back and neck), three elbow or shoulder dislocations (one each in aerial skiing, slopestyle and halfpipe snowboard),
- three unclassified injuries to the lumbar spine and hip regions, two cartilage or meniscus lesions (one to the knee in alpine skiing and one to the lumbar spine in ice hockey),
- two tendon ruptures (to the knee in alpine skiing and thigh in bobsleigh),
- two lower back muscle cramps or spasms (in biathlon and cross-country skiing),
- one nerve/spinal cord injury to the thoracic spine in ski cross,
- one bone bruise injury to the knee in alpine skiing,
- one laceration to the face in ice hockey, and
- one Achilles tendinopathy in biathlon.

Of the 11 reported concussions, six were estimated to lead to more than seven days of absence (two in halfpipe skiing, two in slopestyle snowboard, one in snowboard cross, and one in an unclassified freestyle skiing event).

Mechanisms and circumstances of injury

While 81% (n=315) of the injuries were reported to occur acutely, 19% (n=76) were reported to be caused by an overuse mechanism. The three most commonly reported injury mechanisms were contact with a stationary object (25%), overuse with gradual onset (14%), and non-contact trauma (13%).

Contact with a stationary object was the most frequent mechanism of injury in ski cross (63%), snowboard slopestyle (59%), snowboard halfpipe (50%), halfpipe skiing (50%), aerial skiing (47%), snowboard slalom (44%), moguls skiing (36%), snowboard cross (33%), and ski slopestyle (31%), and alpine skiing (26%). Similarly, in ice hockey, contact mechanisms accounted for 77% of the injuries, with contact with another athlete accounting for 40% of the injuries, contact with a moving object accounting for 23% of the injuries, and contact with a stationary object accounting for 13% of the injuries.

Overuse with gradual onset was conversely the most frequent mechanism of injury in curling (75%), bobsleigh (35%), cross-country skiing (26%), and figure skating (25%). Of all overuse injuries (gradual and sudden onset) occurring in the Games, 75% were recorded with no estimated absence from competition or training.

Of all the injuries, 35% were sustained in competition (8.8 [7.7-9.9] injuries per 100 athletes) and 63% during training (4.8 [4.0-5.7] injuries per 100 athletes), indicating an 82% higher rate of injury in training (RR=1.82 [1.47-2.24], P<0.0001)[*]. However, when analysing only the severe injuries, estimated to result in at least seven days of absence, no difference was found, with competition accounting for 56% of the injuries and training for 42% (RR=0.74 [0.47-1.15], P= 0.1812)[†].

Injuries in training and in competition differed significantly in characteristics (location, type, mechanism, and subsequent time loss from sport) and in terms of rates in different sports (Table 1). The rate of injury was higher in training than in competition in aerial skiing (RR=3.20 [1.17-8.74], P=0.0232), alpine skiing (RR=3.20 [1.80-5.71], P< 0.0001), bobsleigh (RR=6.75 [2.36-19.29], P=0.0004), figure skating (RR=8.50 [1.96-36.80], P=0.0042), and luge (RR=8.00 [1.00-64.00], P=0.0499). When including only injuries estimated to lead to at least seven days of absence, the higher injury rate in training remained only for alpine skiing (RR=11.0 [1.42-85.20], P=0.0217).

Ice hockey was the only sport in which the competition injury rate was higher than the training injury rate (RR=0.48 [0.25-0.83], P=0.0095), a difference which increased when isolating the injuries estimated to result in more than seven days of absence (RR=0.15 [0.04-0.68], P=0.0137).

Incidence and distribution of illnesses

Among the 2788 exposed athletes, a total of 249 illnesses were reported, resulting in an incidence of 8.9 illnesses [95% CI: 7.8-10.0] per 100 athletes (Table 1). On average, 8% (n=229) of the athletes incurred an illness, as there were nine athletes with two illnesses each.

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[*] Information on training/competition missing in 11 injuries

† Information on training/competition missing in 2 injuries

Female athletes (10.9 illnesses [9.0-12.9] per 100 athletes) were at significantly higher risk of contracting an illness than male athletes (7.3 [6.0-8.6], RR=1.5 [1.17-1.93], P= 0.0015).

Illnesses were reported from a variety of sports. Skeleton was the sport with the highest illness rate (27.7 illnesses [95% CI 12.6-42.7] per 100 athletes). It was followed by short track (14.2 [7.0-21.3]), curling [14.0 [6.7-21.3]), cross-country skiing (13.8 [9.6-18.0]), figure skating (12.1 [6.5-17.7]), bobsleigh (11.7 [6.6-16.8]) and aerial skiing (11.6 [1.4-21.8]) (Table 1). The illness rates were lowest in snowboard slalom, moguls skiing, ski jumping, snowboard slopestyle, luge, snowboard halfpipe and snowboard cross (incidence rates ranging from 1 to 4 illnesses per 100 athletes).

Affected system, causes, and severity of illness

A total of 159 illnesses (64%) affected the respiratory system, and these were most frequently observed in skeleton (21% of the athletes), cross-country skiing (10%), curling (8%), biathlon (8%), bobsleigh (8%), short track (7%), and Nordic combined (7%). The second, third and fourth most frequently affected systems were the digestive system (n=28, 11%), nervous system (n=13, 5%), skin and subcutaneous tissue (n=12, 5%), and genitourinary system (n=9, 4%), respectively.

Infection was the most common cause of illness (n=145, 58%), affecting athletes in mainly the same sports as mentioned above. Of the 159 respiratory illnesses, 118 (74%) were caused by an infection.

One in four illnesses (n=63, 25%) were expected to result in absence from training or competition. Of these, two illnesses (1%) were expected to result in an estimated time loss of more than seven days (one upper respiratory tract infection; and one illness affecting the nervous system).

Rate of response, injury and illness per NOC size

Thirty-four of the 88 NOCs had more than 10 participating athletes. Athletes from these NOCs comprised 2623 of the in total 2779 athletes competing for an NOC, corresponding to 94% (Table 3). Throughout the 18 days of the Sochi Games, the 34 NOCs submitted a total of 610 of a maximum of 612 forms (mean 99.7%, range 89-100%).

Only 17% of the injuries and 2% of the illnesses were captured by both the NOCs and the Sochi 2014 staff. While 49% of the injuries and 68% of the illnesses were recorded solely by the NOCs, 34% and 30% of the injuries and illnesses, respectively, were recorded only by the Sochi 2014 staff.

Whereas the majority of injured and ill athletes from the larger NOCs were seen internally by the NOC medical staff, athletes from smaller NOCs were to a greater extent relying on diagnosis and treatment from the Sochi 2014 medical staff (Table 3).

There was also an inverse relationship between NOC size (measured in number of participating athletes) and the risk of health problems, with athletes from smaller NOCs experiencing higher injury and illness rates (NOCs with <10 athletes: 30.1 [21.5-38.7] injuries and 14.1 [8.2-20.0] illnesses per 100 athletes vs. NOCs with >99 athletes: 10.5 [9.0-12.0] injuries and 8.1 [6.8-9.4] illnesses per 100 athletes, injury RR=2.87 [2.08-4.00], illness RR=1.74 [1.11-2.73]).

Discussion

The aim of the present paper was to describe and analyse the injury and illness rates and characteristics in the Sochi 2014 Olympic Games. The main findings of this 18-day long prospective cohort study were that 12% and 8% of all the 2780 athletes suffered from at least one injury or illness, with overall rates of 14.0 injuries and 8.9 illnesses per 100 athletes, respectively. The magnitude and characteristics of the injuries and illnesses varied substantially between sports and gender.

While the highest injury rates were found in snow sports characterised by aerial maneuvers and high-speed, namely aerial skiing (49% of all athletes injured), slopestyle snowboard (37%), snowboard cross (34%), slopestyle skiing (31%), halfpipe skiing (26%), moguls skiing (25%), alpine skiing (21%), and snowboard halfpipe (18%), the highest rates of illness were found in ice sports such as skeleton (28%), short track (14%), curling (14%), figure skating (12%), bobsleigh (12%), as well as in cross-country skiing (14%).

Injury incidences in the Olympic sports

The overall rate of injury in the Sochi Games was slightly higher than in Vancouver 2010 and in London 2012 (12% of all athletes injured in Sochi versus 11% in Vancouver and London).[12, 13] Furthermore, compared to their Vancouver Games counterparts, higher injury rates were found in the Sochi Games athletes competing in aerial skiing (49% vs. 19% of the athletes injured), alpine skiing (21% vs. 15%), biathlon (7% vs. 1%), cross-country skiing (8% vs. 3%), curling (12% vs. 4%), luge (8% vs. 2%), moguls skiing (25% vs. 2%), skeleton (11% vs. 6%), snowboard halfpipe (18% vs. 13%), and snowboard slalom (14% vs. 7%). Conversely, lower injury rates were found among the Sochi Games athletes competing in ice hockey (11% vs. 18%), short track (9% vs. 18%), and ski cross (14% vs. 19%). In general, our findings on the sports-specific injury rates in Sochi are corroborated by a large body of research from the FIS World Cup, where snowboard cross and halfpipe,[47] aerial and halfpipe skiing and ski cross,[43] as well as particularly downhill of the alpine skiing events [42, 46] have been identified as high-risk disciplines.

A change in injury incidence can be the result of changes in environmental factors such as snow or ice conditions, venue or track design, competition rules, in equipment, or other factors. Changes in injury rates can also follow an increased or reduced awareness among both the athletes and their medical staff in recognizing and reporting even minor incidents (broad injury and illness definition applied in IOC surveillance studies). In certain sports, changes may also be attributable to more comprehensive and accurate data reporting by team physicians who over time have been trained as injury and illness recorders through the implementation of surveillance systems by their own Federation. Also, rate differences (lower or higher) may simply be the result of a natural fluctuation/variability of athlete´s exposure to risk, an observation that emphasizes the value of on-going surveillance to monitor trends over time, e.g. the effect of venue design, rule or equipment changes in the period between major sports events.

Severity, location and type of injuries

In major sports events, like the Olympic Games, injuries or illnesses of even minor severity and time loss have the potential to be both participation-limiting and performance-inhibiting, and thus prevent athletes from reaching their life-time achievement. In the Sochi Games, 61% of the injuries were reported to lead to no absence from competition or training, whereas 39% were estimated to result in time loss of at least one day. However, as many as 21% of the injuries were estimated to encompass time loss greater than seven days. This indicates a significant shift from the Vancouver Games, where 23% of the injuries were expected to entail a time loss of at least one day, and just 4% a time loss of more than seven days, albeit there was a high percentage of missing data on injury severity in Vancouver.[12]

The high rates of serious injuries cause special concern, and may warrant a more extensive recording and detailed analysis of injury risk factors and mechanisms, to protect athletes in these sport events in the future.

The risk of concussion is a recurrent concern in certain sports, and its diagnosis, prevention, treatment, and return-to-play guidelines have been addressed in recent consensus meetings.[52, 53] Eleven concussions were recorded in Sochi (0.4% of the athletes). Although this is half of the 20 concussions (0.8%) reported in Vancouver, it is considerably higher than the rates reported from the Summer Olympics in London (n=6, 0.06% of athletes) and Beijing (n=12, 0.11%). This finding supports the hypothesis that winter sports athletes, particularly those exposed to aerial maneuvers and high speeds are at higher risk of potentially severe head injuries than their summer-sports counterparts.

Mechanisms and circumstances of injury

The mechanisms and circumstances of injuries in competition and training differed significantly between the different sports. With 63% of the injuries occurring during training and only 35% in competition, the findings differ from those in the Vancouver Games, where the distribution was relatively even (54% versus 46%, respectively).[12] It is likely that this change is explained by differences in venue conditions (e.g. snow, ice, jumps), but we do not have data to identify the exact causes.

A pattern seems to emerge where winter sports athletes might suffer a slightly higher proportion of injuries in training, whereas their summer sports counterparts sustain more injuries in competition.[13, 23, 37-39, 43, 47, 51] The exception might be ice hockey, which was the only sport on the Sochi Olympic program in which the majority of injuries occurred in competition, an effect which was even greater when including only the injuries estimated to result in more than seven days of time loss. These results are in correspondence with earlier epidemiologic findings.[54-58] Ice hockey is a team and collision sport, where the intensity, speed of play, number of body checks and fatigue are considerably higher in games – where more is at stake – than in training, where a significant amount of time is used for recovery and training drills of lower intensity.

The majority of injuries in Sochi were reported to be acute, whereas overuse injuries with either a gradual or sudden onset accounted for about one fifth of the injuries. Similar distributions have been reported from both the summer and winter Olympic Games previously;[12, 13, 51] however, these numbers should be interpreted with caution, due to the current limitations in the recording of overuse injuries.[59]

Illness risk during the Olympics

The rate of illness in the Sochi Games was slightly higher than those reported in the Vancouver Games and London Games (8% of all athletes affected in Sochi versus 7% in Vancouver and London).[12, 13] Also consistent with the Vancouver and London data is the difference in the incidence of illnesses between female and male athletes, with female athletes in Sochi contracting 50% more illnesses than male athletes. The same disproportion has previously been reported in the 2009 athletics[38] and aquatics[40] world championships, but not in the 2011 athletics world championships,[39] in the 1994-2009 US Open tennis championships,[60] or in the Summer Paralympic Games.[14]

The high incidence of respiratory infections mirrors data from other elite sport events.[14, 15, 23, 38-40, 60-65] Predominant risk factors are mechanical and dehydration stresses generated within the airways and the level of airborne pollutants, irritants, and allergens inhaled by the athlete under high ventilatory exercise conditions.[66] Earlier it has been reported that airway hyperresponsiveness/asthma is one of the most common chronic medical conditions in both winter and summer elite sports, especially among endurance athletes.[67] Team physicians can anticipate that athletes travelling intercontinentally are at higher risk of illness,[63] but that these illnesses can be mitigated through careful planning and diagnostic work prior to the Games.[68]

Methodological considerations

In studies on sports injury, it is usually recommended to express incidences using time exposed to risk as the denominator.[69, 70] However, considering the inherent complexity and size of the Olympic Games, this was not feasible in the present study. Instead, we expressed the incidence of injury or illnesses by means of absolute risk: the number of new cases per 100 registered athletes. This approach assumes that the number of athletes at risk in each NOC is constant throughout the Games. With the aim of improving the accuracy of the exposure data, it has been recommended to rather record and utilise athlete exposure days, that is, the actual number of days throughout the Games in which an athlete is exposed to the sport and being under care of the medical team.[14, 15, 36] This approach may better facilitate comparison with other events of more or fewer days of duration. It also takes censorship into account, such as abbreviated lengths of exposure for reasons other than injury or illness (such as late arrivals or early departures due to competition schedules), albeit it has been shown in the Paralympic Games that the variation between the actual number of exposed athletes and the total number of registered athletes in each delegation is negligible.[15]

However, the weakness of both aforementioned approaches is that they fail to account for the paramount challenge of exposure in multi-sport events, namely the different frequencies and lengths of exposure in each sport and discipline. For example, a cross-country skier's exposure to competition and training – and the encompassing risk of injury or illness – is by nature very different to that of an ice hockey player, snowboarder or figure skater. Even disciplines within the same sport are affected by this problem: in alpine skiing it has recently been documented how previously reported higher risks of injury in downhill may very well not only be explained by higher speed, but also by a bias of total exposure time.[71] As current recording of exposure in multi-sports events ignores this exposure bias, interpretation of differences in injury incidences or patterns should be made with a high degree of caution.

The ideal recording of exposure in any sport or multi-sport event comprises measurement of\the accurate time (minutes or seconds) each athlete is exposed to the sport and its inherent risks. Injury and illness rates can be reported both as the number of new cases per appropriate unit of time and as absolute risk. Taking into consideration current technological limitations and the manual workload it would require to collect such comprehensive data, this is not yet feasible in multi-sport events like the Olympic Games. The development of sophisticated electronic systems with automated processes for measuring athletes' participation in all parts of a multi-sports training and competition may enable the recording of refined exposure data in the future, and will facilitate an encompassing uniform reporting and comparison of incidences of injuries and illnesses in sports.

Recent papers from Bahr[59] and Clarsen et al.[72, 73] highlight the inadequacy of the current standard epidemiological methodology to record the true magnitude and pattern of overuse injuries in sport. As pointed out by Bahr,[59] overuse injuries may in many sports represent as much of a problem as do acute injuries, but these injuries are seldom properly captured or registered in statistics through current recording methods, as athletes with overuse problems often do not seek medical attention or lose time from training or competition. In the present study, overuse was reported to be the mechanism for every fifth injury, with notable presence in curling, bobsleigh, alpine skiing, cross-country skiing, figure skating and biathlon. Furthermore, 75% of the overuse injuries in Sochi were recorded with no estimated absence, an indication that – also in the Olympic setting – athletes with overuse problems often continue to training and compete, although typically with significant inhibitions, such as pain, restricted function and reduced performance. It will be important in the future to assess the concept and methodology of the injury and illness surveillance in the Olympic Games, to identify whether it is possible to better capture these data.[74]

In the current study we defined injuries and illnesses as new or recurring injuries or illnesses receiving medical attention, regardless of the consequences with respect to absence from competition or training. By using such a definition, predominantly the moderate and severe acute injuries will be recorded. The less serious injuries may be overlooked, since such injuries do not always require medical attention,[75, 76] albeit our results show that the majority of reported injuries were not estimated to involve any absence from the sport. In the Olympic Games, all athletes can get health care through the athletes' village polyclinic and the venue medical clinics. However, the availability, size and quality of the NOCs own medical teams vary between countries, meaning that not all athletes benefit from the same easy access to health care, which may bias the injury and illness recording.

Throughout the 18 days of data collection in the Olympic Games, we collected 99.7% of all the NOC injury and illness report forms. This is the highest NOC response rate to date in the

Olympic Games injury and illness surveillance, a result which can be attributed to favourably disposed NOC medical staff, an informational meeting with all NOCs the day before the Games' opening, the preparation of report forms in seven languages and an instructional booklet on how to fill in the forms, and a dedicated and increasingly experienced research team which conducted frequent follow-up visits to boost NOCs' compliance. However, although the NOC response rate was excellent, we did not test the accuracy and internal validity of their reported data. Thus, we cannot know the extent to which the NOC data match the actual circumstances of the occurred injury or illness. An indication of this is that a number of injuries and illnesses were recorded in an incomplete manner with missing information in categories such as circumstance and diagnosis. Furthermore, it has been documented earlier in professional alpine skiing[44] and male elite football[77] that prospective injury surveillance by team medical staff underestimates the incidence of injuries and time-loss injuries. Our results support these findings, as the NOC medical teams failed to report 34% and 30% of the total reported injuries and illnesses, respectively.

The same result demonstrates how recording data both among NOC medical staff and in the organising committee's medical stations is absolutely vital to the scientific quality of the surveillance study. A mere 17% of the injuries and 2% of the illnesses were captured by both recorder groups. Our study also shows that in particular athletes from smaller NOCs benefit from diagnosis and treatment from the local organising committee's medical staff, whereas the majority of athletes from larger NOCs are seen by their own NOC medical staff. More importantly, we identified an inverse relationship between NOC size and the risk of health problems, with athletes from the smallest NOCs experiencing an almost threefold injury rate and twofold illness rate compared with the largest NOCs. It is difficult not to see this finding in light of distinct differences in resources available to the NOC.

Practical implications

The epidemiology of injuries in the Sochi and Vancouver Olympic Games[12] and the FIS World Cup [43, 45, 47, 49] has demonstrated a critically high risk of severe injuries in many of the snowboarding and freestyle skiing events, constituting a significant problem for the sports and athletes. Likewise, in recreational freestyle skiing and snowboarding, it has been found that the rate of severe injuries, in the form of spine and head injuries, is double inside terrain parks compared with outside.[78] Furthermore, it has recently been demonstrated that a preponderance of the injuries occur in jumps, kickers and the halfpipe, in other words, in features that facilitate aerial manoeuvres.[17, 48, 79] In order to mitigate the risk of these injuries, we need more refined data on their sport-specific risk factors and mechanisms. Interestingly, it is recurrently hypothesized anecdotally by athletes and coaches that a number of the injuries are caused by unfavourable design characteristics of the snow park jumps and landings. This is supported by our data, which, although crude, show that a large part of the injuries are caused by contact to a stationary object (such as the ground).[12] Furthermore, we know that the magnitude of impact risk can be characterised by the equivalent fall height, a measure of jumper impact velocity normal to the slope, and that design algorithms exist to calculate landing surface shapes that limit this equivalent fall height to arbitrarily low values – but that these rarely are used when building jumps.[80-82] It has been asserted that terrain park jump analysis and design are futile due to rider and snow variability,[83] but recent papers have demonstrated how constant equivalent fall height jumps can be designed and maintained despite variations in other parameters,[84] and that such jumps are practical to build using standard snow grooming machines.[85] Although the risk of injury undoubtedly is a function comprised of a number of factors, these recent advances in the understanding of jump designs and injury risk constitute one example where concerted efforts among sports federations, local organisers and ski areas to develop and adopt standards for terrain park design and jump landing safety could lead to a reduction of injury in the sports.

The IOC is currently developing a customised electronic medical record (EMR) for the Rio 2016 Games and beyond to replace the medical encounter tool used by the local organising committees since the Barcelona 1992 Games. The implementation of the EMR will not only improve the health care provision in the Olympic and Paralympic Games, but also provide a number of new opportunities to the recording of injuries and illnesses in a confidential manner. With time, NOC physicians and physiotherapists will be able to record their daily injury and illness data, feeding into the same EMR database, possibly rendering the IOC paper record forms obsolete. Data privacy will evidently be of high importance, with anonymized data accessible strictly to authorised users. In the long term, our aim is to invite NOCs to use the same EMR in their daily medical follow-up of their athletes in between the Games. An electronic injury and illness surveillance will also facilitate advances in the quality and usefulness of the data that we capture. For example, one will be able to record risk factors and mechanisms that are specific to each sport and event, which will significantly improve our ability to subsequently ideate and tailor injury prevention initiatives.

The continuously accumulating evidence that injury and illness rates vary substantially between sports demonstrates the need for tailoring preventive measures to the specific context of each sport. Sport bodies such as the IOC, International Paralympic Committee (IPC), International Sports Federations (IFs) and NOCs have the responsibility to protect the health of their athletes. The Olympic Movement Medical Code encourages all stakeholders to take measures to ensure that sport is practised with minimal risks of physical injury and illness or psychological harm.[86] For NOCs one evident way of achieving this is by introducing periodic health evaluations (PHEs) in their daily practice, which are instrumental to preventing injuries and illnesses, and hence, to protect the health of the athletes.[87] For IFs, a critical component of this responsibility is the institution of a scientifically sound injury and illness surveillance system in all major events. Some sports federations, such as FIFA (Fédération Internationale de Football Association), FINA (Fédération Internationale de Natation), FIS (Fédération Internationale de Ski), FIVB (Fédération Internationale de Volleyball), IAAF (International Association of Athletics Federations), IIHF (International Ice Hockey Federation), IRB (International Rugby Board) and UEFA (Union of European Football Associations) have put increasing effort into working systematically and scientifically to protect their athletes' health. We encourage other IFs and sports organisations to follow their example.

Conclusion

In summary, 12% of the athletes incurred an injury during the London Olympic Games, and 8% suffered from at least one illness. The incidences and characteristics of injuries and illnesses in training and competition varied substantially between sports and gender. Future initiatives will include the recording of sport-specific injury and illness risk factors and mechanisms, to better inform the development of tailored prevention measures targeting the athlete at risk.

Table 1. Rates of injuries overall, injuries leading to time loss (≥1 day or >7 days of estimated absence), competition and training injuries, and illnesses overall in the Olympic sports. Values presented are numbers (and incidences in brackets) of injured or ill athletes.

Olympic sport	Athletes (n)	Injuries					All illnesses
		All	≥1 day	>7 days	Competition	Training	
Ice sports							
Curling	100	12 (12.0)	1 (1.0)	1 (1.0)	8 (66.7)	4 (33.3)	14 (14.0)
Ice hockey	466	52 (11.2)	25 (5.4)	15 (3.2)	35 (67.3)	16 (30.8)	26 (5.6)
Skating							
Figure	149	20 (13.4)	2 (1.3)	1 (0.7)	2 (10.0)	17 (85.0)	18 (12.1)
Short track	106	9 (8.5)	4 (3.8)	1 (0.9)	7 (77.8)	2 (22.2)	15 (14.2)
Speed	177	8 (4.5)	3 (1.7)	-	2 (25.0)	1 (12.5)	17 (9.6)
Ice track							
Bobsleigh	171	31 (18.1)	5 (2.9)	2 (1.2)	4 (12.9)	27 (87.1)	20 (11.7)
Luge	108	9 (8.3)	1 (0.9)	-	1 (11.1)	8 (88.9)	3 (2.8)
Skeleton	47	5 (10.6)	-	-	1 (20.0)	4 (80.0)	13 (27.7)
Snow sports							
Alpine skiing	314	65 (20.7)	29 (9.2)	12 (3.8)	15 (23.1)	48 (73.8)	27 (8.6)
Freestyle skiing							
Aerials	43	21 (48.8)	6 (14.0)	4 (9.3)	5 (23.8)	16 (76.2)	5 (11.6)
Halfpipe	51	13 (25.5)	6 (11.8)	4 (7.8)	3 (23.1)	10 (76.9)	4 (7.8)
Moguls	57	14 (24.6)	10 (17.5)	5 (8.8)	6 (42.9)	7 (50.0)	1 (1.8)
Ski cross	59	8 (13.6)	6 (10.2)	6 (10.2)	5 (62.5)	2 (25.0)	4 (6.8)
Slopestyle	52	16 (30.8)	6 (11.5)	4 (7.7)	4 (25.0)	12 (75.0)	3 (5.8)
Snowboarding							
Halfpipe	66	12 (18.2)	3 (4.5)	2 (3.0)	5 (41.7)	7 (58.3)	2 (3.0)
Slopestyle	46	17 (37.0)	12 (26.1)	5 (10.9)	4 (23.5)	12 (70.6)	1 (2.2)
Snowboard cross	61	21 (34.4)	10 (16.4)	8 (13.1)	9 (42.9)	11 (52.4)	2 (3.3)
Slalom	64	9 (14.1)	2 (3.1)	2 (3.1)	2 (22.2)	7 (77.8)	1 (1.6)
Nordic skiing							
Biathlon	204	14 (6.9)	5 (2.5)	2 (1.0)	4 (28.9)	10 (71.4)	20 (9.8)
Cross-country skiing	297	23 (7.7)	7 (2.4)	3 (1.0)	9 (39.1)	13 (56.5)	41 (13.8)
Nordic combined	54	2 (3.7)	2 (3.7)	2 (3.7)	1 (50.0)	1 (50.0)	5 (9.3)
Ski jumping	96	7 (7.3)	4 (4.2)	2 (2.1)	2 (28.6)	5 (71.4)	2 (2.1)
Total	2788	391 (14.0)[a]	151 (5.4)	82 (2.9)	135 (34.5)[b]	245 (62.7)[b]	249 (8.9)[a]

[a]Information on sport/event missing in 3 injuries and 5 illnesses. [b]Information on training/competition is missing in 11 injuries. Data include 8 double-starters.

Table 2. Rates of injuries overall and injuries leading to time loss (>7 days of estimated absence) in female and male athletes in the Olympic sports. Values presented are numbers (and incidences in brackets) of injured or ill athletes.

Olympic sport	Female athletes			Male athletes		
	n	All injuries	Time loss >7 days	n	All injuries	Time loss >7 days
Ice sports						
Curling	50	5 (10.0)	1 (2.0)	50	7 (14.0)	-
Ice hockey	168	19 (11.3)	3 (1.8)	298	32 (10.7)	12 (4.0)
Skating						
Figure	74	10 (13.5)	-	75	10 (13.3)	1 (1.3)
Short track	50	3 (6.0)	-	56	6 (10.7)	1 (1.8)
Speed	83	3 (3.6)	-	94	5 (5.3)	-
Ice track						
Bobsleigh	40	9 (22.5)	1 (2.5)	131	22 (16.8)	1 (0.8)
Luge	31	3 (9.7)	-	77	6 (7.8)	-
Skeleton	20	2 (10.0)	-	27	3 (11.1)	-
Snow sports						
Alpine skiing	130	27 (20.8)	4 (3.1)	184	38 (20.7)	8 (4.3)
Freestyle skiing						
Aerials	22	12 (54.5)	2 (9.1)	21	9 (42.9)	2 (9.5)
Halfpipe	23	5 (21.7)	2 (8.7)	28	8 (28.6)	2 (7.1)
Moguls	28	10 (35.7)	4 (14.3)	29	4 (13.8)	1 (3.4)
Ski cross	28	5 (17.9)	4 (14.3)	31	3 (9.7)	2 (6.5)
Slopestyle	22	11 (50.0)	2 (9.1)	30	5 (16.7)	2 (6.7)
Snowboarding						
Halfpipe	27	8 (29.6)	2 (7.4)	39	4 (10.3)	-
Slopestyle	21	7 (33.3)	3 (14.3)	25	10 (40.0)	2 (8.0)
Snowboard cross	23	10 (43.5)	5 (21.7)	38	11 (28.9)	3 (7.9)
Slalom	32	6 (18.8)	2 (6.3)	32	3 (9.4)	-
Nordic skiing						
Biathlon	99	5 (5.1)	-	105	9 (8.6)	2 (1.9)
Cross-country skiing	125	8 (6.4)	2 (1.6)	172	15 (8.7)	1 (0.6)
Nordic combined	-	-	-	54	2 (3.7)	2 (3.7)
Ski jumping	30	-	-	66	7 (10.6)	2 (3.0)
Total	1126	168 (14.9)[a]	37 (3.3)	1662	219 (13.2)[a]	44 (2.6)

[a]Unknown gender for 4 injuries. Data include 8 double-starters.

Table 3. Response rates, injuries and illnesses in NOCs of different sizes (measured by number of athletes).

	<10	10-49	50-99	>99	All
NOCs (athletes)	54 (156)	12 (258)	10 (622)	12 (1743)	88 (2779[a])
Injuries (injuries per 100 athletes)	47 (30.1)	67 (26.0)	93 (15.0)	183 (10.5)	390[b] (14.0)
Illnesses (illnesses per 100 athletes)	22 (14.1)	44 (17.1)	42 (6.8)	141 (8.1)	249 (9.0)
Report forms submitted[c] (%)	-	216 (100.0)	178 (98.9)	216 (100)	610 (99.7)
Recorded by both NOC and OCOG					
Injuries	9 (19.1)	11 (16.4)	14 (15.1)	34 (18.6)	68 (17.4)
Illnesses	1 (4.5)	-	1 (2.4)	2 (1.4)	4 (1.6)
Recorded only by NOCs					
Injuries	6 (12.8)	27 (40.3)	50 (53.8)	107 (58.5)	191 (49.0)
Illnesses	3 (13.6)	24 (54.5)	31 (73.8)	112 (79.4)	170 (68.3)
Recorded only by OCOG					
Injuries	32 (68.1)	29 (43.3)	29 (31.2)	42 (23.0)	132 (33.8)
Illnesses	18 (81.8)	20 (45.5)	10 (23.8)	27 (19.1)	75 (30.1)

[a]1 Independent Olympic Athlete and 8 double-starters excluded; [b]NOC is missing for 1 injury; [c]Countries with less than 10 athletes were excluded from the response rate analysis.

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