©Journal of Sports Science and Medicine (2023) **22,** 748-759
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2023.748

Review article

Exploring the Epidemiology of Injuries in Athletes of the Olympic Winter Games: A Systematic Review and Meta-Analysis

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Abstract
This study sought to provide a comprehensive assessment of the incidence of sports injuries among athletes participating in the Olympic Winter Games and to investigate contributing factors. We gathered injury data from athletes participating in the recent four Olympic Winter Games, incorporating details on the sports event, sex, injury location, and type. Through a meta-analysis, we calculated the injury incidence rates for each sport and examined the influence of sex and the type of sport on these incidence rates. Out of 11,197 registered athletes, we documented 1,304 sports injuries. The sports events with the highest injury rates were freestyle skiing, snowboarding, alpine skiing, bobsleigh, and ice hockey, with the most frequent injury locations being the knees, thoracic/lumbar/back regions, and the wrist/hand/fingers. Contusions, hematomas, and bruises were the most prevalent injuries, followed by strains (including muscle rupture, tearing, or tendon rupture) and sprains (covering dislocations, subluxations, and ligament ruptures). In the Olympic Winter Games, events such as freestyle skiing, snowboarding, alpine skiing, bobsleigh, and ice hockey pose a particularly high risk. Predominant injury sites include the knee, spine/back, and wrist and hand, with injuries ranging from contusions and hematomas to strains and sprains. For effective injury prevention, it is crucial to emphasize proper medical resource allocation, specialized training for medical personnel, and meticulous venue maintenance.

Key words: Olympic winter games, sports injury, athlete, epidemiology.

Introduction

Regular exercise is widely recognized for its considerable health benefits, which include a reduced risk of premature death (Ekelund et al., 2019), decreased incidence of cardiovascular diseases (Fiuza-Luces et al., 2018), enhanced physical functionality, improved fitness levels (Dibben et al., 2018), bolstered immunity (Simpson et al., 2021), and augmented mental health (Fossati et al., 2021). These advantageous effects persist in elite athletes despite their increased athletic exertion and participation in high-intensity competitions. Current evidence suggests that these athletes may demonstrate a lifespan extending beyond the average expectancy, accompanied by a reduced susceptibility to disease and hospitalization (Clarke et al., 2015; Teramoto and Bungum, 2010; Zwiers et al., 2012). However, a paradox presents itself in the form of heightened risk of both acute and chronic musculoskeletal ailments attributable to intense sporting activities (Bell et al., 2018).

The Olympic Winter Games, a quadrennial event, predominantly encompass a plethora of winter sports activities conducted on snow and ice. The snow-based events incorporate diverse disciplines of skiing such as cross-country, ski jumping, Nordic combined, alpine, freestyle, snowboarding, and winter biathlon, while the ice-based competitions comprise ice hockey, assorted types of skating (speed skating, short track speed skating, figure skating), curling, and an array of sledding events (steered sled, snowmobile, un-steered sled). Winter sports, defined by their unique environmental requirements, high-speed movements, broad range of turns, intricate technical maneuvers, and extended airborne durations, serve to enhance participants' core and general strength, reaction time, agility, and resistance to cold. However, these high-intensity activities also inevitably give rise to a multitude of sports-related injuries (Gabbett and Ullah, 2012). Furthermore, the equipment utilized in Olympic Winter sports, while tailored for performance, can at times contribute to injuries. Badly fitted or improperly used gear can exacerbate risks, with even minor maladjustments leading to increased risk during competition and training.

Protecting the health of athletes and mitigating health risks, while preserving the integrity of sports, is a paramount responsibility for all sports federations (Soligard et al., 2019). An essential component of this protection is understanding injury epidemiology and etiology, which has been found to play a significant role in injury prevention (Xu et al., 2020). Systematic injury and disease monitoring may track trends over time, identify high-risk sports as well as the most prevalent and severe injuries and diseases, and provide valuable knowledge to reduce the risk. Therefore, to maximize the health benefits of elite athletes and minimize the direct and indirect costs associated with injuries, identifying athletes at elevated risk of injury, and providing them with strategies to prevent sports injuries is an important goal. Major sports events are excellent windows to understand winter sports injuries, but due to differences in injury definitions, data collection methods, research designs, etc., injury data from different periods cannot be compared in many aspects. As a result, the IOC developed an injury monitoring system during the 2008 Olympic Games (Junge et al., 2008), which unified the

Received: 19 June 2023 / Accepted: 06 November 2023 / Published (online): 01 December 2023

definition of injuries, reporting forms, and methods, enabling good comparability of injury data from different periods, creating conditions for obtaining epidemiological information, preventing injuries, and monitoring injury trends. Subsequently, this system has been employed for injury surveillance during the Olympic Winter Games (Ruedl et al., 2016).

However, these reports often focus solely on individual or a select few events and categories, leaving a void in the comprehensive summary of injury epidemiology among winter sports athletes. In this study, we collate and scrutinize the sports-related injuries of athletes from the most recent four Olympic Winter Games. We perform a retrospective statistical analysis of injury incidence, locations, and types, as well as injury locations and types in various events. This study thereby furnishes a valuable reference for winter sports athletes, coaches, medical staff, and researchers immersed in the field of sports injury epidemiology.

Methods

This systematic review and meta-analysis were conducted in strict compliance with the PRISMA guidelines and were registered with the PROSPERO database under the identification number CRD42023417198.

Literature search method

Two researchers independently executed the search using a predetermined strategy, surveying databases such as Web of Science, PubMed, and EMBASE. The search period spanned from 2010 to April 2023, employing the terms "Olympic Winter Games" and "injury, trauma."

Inclusion criteria

Scope of Study: The study must report on injuries at the Olympic Winter Games, covering the incidence, location, and type of injuries; Population: Only studies focusing on professional athletes were considered; Language Restrictions: There were no language restrictions applied; Availability: Full-text availability of the study was mandatory; Study Design: The selected study design was observational cohort study.

Exclusion criteria

Duplicate publications: To avoid data redundancy and potential biases, studies with overlapping datasets were excluded; Studies focusing solely on a single sport or athletes from one country: Given our aim for a broad representation of the Olympic Winter Games, studies limited to a single sport or country were excluded to mitigate potential biases; Studies unrelated to the Olympic Winter Games: To maintain the focus and relevance of our review, only studies directly pertaining to the Olympic Winter Games were considered; Studies with incomplete or inaccessible data: To ensure the integrity and robustness of our meta-analysis, studies lacking comprehensive data or where essential data were unavailable were excluded.

Literature screening and data extraction

Two researchers independently performed literature screening and data extraction based on the above criteria, with the results cross-verified for accuracy. In cases of disagreement, resolution was achieved through discussion or by the intervention of a third researcher. Initial screening involved scrutinizing the title and abstract of articles. After excluding unrelated studies, a thorough examination of full texts was conducted to finalize the inclusion. The data extracted encompassed the sex and number of injured athletes in each sport, as well as the injury location and type.

Quality assessment of included studies

To gauge the quality of the studies, an eleventh-item metric recommended by the US Health Care Research Agency was employed(Zeng et al., 2015). Each item receiving a "no" or "unclear" response was assigned a "0", while a "yes" response was accorded a "1". A cumulative score of 8 - 11 signified high-quality research, a score of 4 - 7 represented medium-quality studies, and a score of 0 - 3 indicated low-quality studies. The third researcher resolved any disagreements.

Statistical analysis

Data were compiled and organized using the 2019 version of Excel. We calculated the incidence of athlete injuries during the Olympic Winter Games by dividing the aggregate number of reported injury cases by the total number of athletes in the respective group, after assimilating similar data. The proportions of injuries of diverse locations or types were computed by dividing the number of reported injury cases of specific locations or types by the overall number of reported cases. Additionally, a meta-analysis was undertaken to scrutinize the incidence of injuries in each sport. The inverse variance weighted model was used to combine the incidence of injuries (Barendregt et al., 2013). I^2 was used to measure heterogeneity (which ranges from 0% to 100%)(Higgins and Thompson, 2002). When I^2 is greater than 50%, we used a arandom effects model, otherwise a fixed effects model was used (Higgins and Green, 2008). All data processing and graphical representations were accomplished utilizing R version 4.1.3.

Results

The articles reporting on the epidemiology of sports injuries from four Olympic Winter Games met the inclusion/exclusion criteria. As shown in Figure 1.

Characteristics of included literature

The scope of this study encompassed Olympic Winter Games events, registered athletes, and the quantity of reported injury cases as demonstrated in Table 1. The data incorporated in the study were sourced from reports by onsite medical stations, designated hospitals, and medical teams of participating countries' Olympic committees. These reports were published in esteemed journals such as the British Journal of Sports Medicine and the World Journal of Emergency Medicine (Engebretsen et al., 2010; Han et al., 2022; Soligard et al., 2015; 2019). The aggregate number of athletes across the four games totaled 11,197.

Quality evaluation of included literature

The quality evaluation of the literature is shown in Table 2.

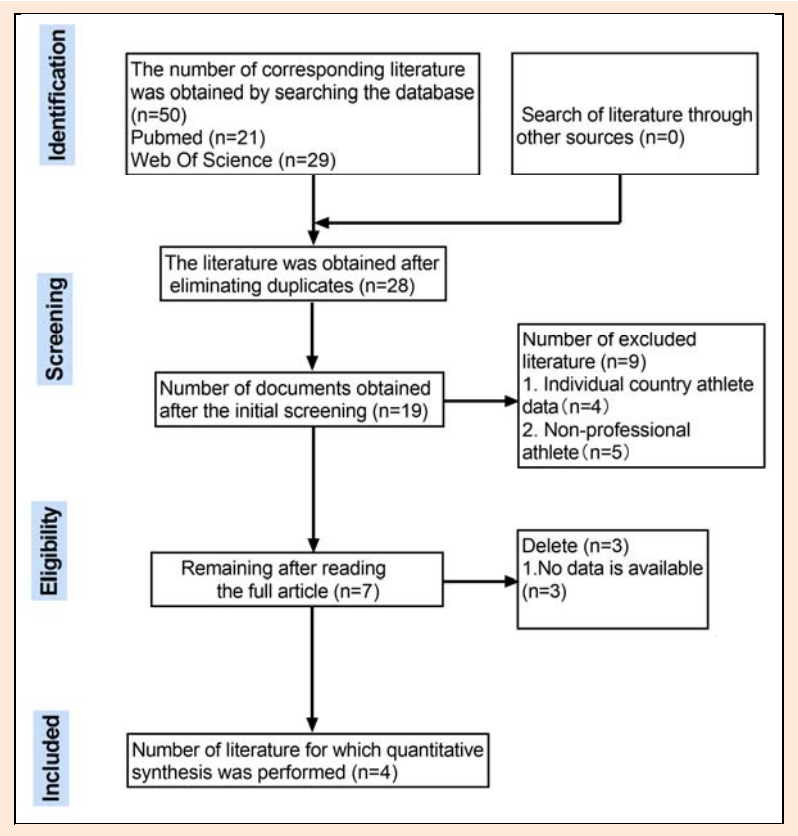

Figure 1. PRISMA flow diagram chart for systematic review and meta-analysis.

Table 1. Characteristics of included studies in the systematic review and meta-analysis on the epidemiology of injuries in athletes of the Winter Olympic Games.

Author	Host year	Host country	Athletes	Female of injury	Male of injury	Major sports events of injury	Study design
Peng-da Han et al	2022	China	2861	123	139	Alpine skiing, Freestyle skiing, Ice hockey	Observational study
Soligard et al	2018	Republic of Korea	2981	169	207	Alpine skiing, Freestyle skiing, Ice hockey	Observational study
Soligard et al	2014	Russian Federation	2788	168	219	Alpine skiing, Freestyle skiing, Snowboarding	Observational study
Engebretsen et al	2010	Canada	2567	137	142	Alpine skiing, Snowboarding, Ice hockey	Observational study

Table 2. Quality assessment of included studies in the systematic review and meta-analysis on the epidemiology of injuries in athletes of the Olympic Winter Games

Author	Host year	1	2	3	4	5	6	7	8	9	10	11
Peng-da Han et al	2022	Yes	Unclear	Yes	Yes	Unclear	Yes	Unclear	Yes	Unclear	Yes	Unclear
Soligard et al	2018	Yes	Unclear	Yes	Yes	Unclear	Yes	Unclear	Yes	Unclear	Yes	Unclear
Soligard et al	2014	Yes	Unclear	Yes	Yes	Unclear	Yes	Unclear	Yes	Unclear	Yes	Unclear
Engebretsen et al	2010	Yes	Unclear	Yes	Yes	Unclear	Yes	Unclear	Yes	Unclear	Yes	Unclear

Define the source of information (survey, record review); (2) List inclusion and exclusion criteria for exposed and unexposed subjects (cases and controls) or refer to previous publications; (3) Indicate time period used for identifying patients; (4) Indicate whether or not subjects were consecutive if not population-based; (5) Indicate if evaluators of subjective components of study were masked to other aspects of the status of the participants; (6) Describe any assessments undertaken for quality assurance purposes (e.g., test/retest of primary outcome measurements); (7) Explain any patient exclusions from analysis; (8) Describe how confounding was assessed and/or controlled; (9) If applicable, explain how missing data were handled in the analysis; (10) Summarize patient response rates and completeness of data collection; (11) Clarify what follow-up, if any, was expected and the percentage of patients for which incomplete data or follow-up was obtained.

Injury incidence in different Olympic Winter Games events

The incidence of sports injuries varies among different Olympic Winter Games events. This includes variations in snow and ice conditions, competition venues, track design, competition rules, competition equipment, and other environmental factors, all of which can cause characteristic differences in sports injuries (Soligard et al., 2015). The study categorized injuries based on different sports events, totaling 1304 injuries, with a combined incidence of 11.6 [95% CI (9.6, 13.6), I^2 = 91,6]. The injury rate of snow events was significantly higher than that of ice events in the statistics obtained from the four Olympic Winter Games. In the four Olympic Winter Games, freestyle

skiing was 18.0 [95% CI (11.6, 24.4), I^2 = 85.0], snowboarding was 17.4 [95% CI (12.2, 22.6), I^2 = 78.3], and alpine skiing was 17.2 [95% CI (11.4, 20.3), I^2 = 53.8]. In contrast, cross-country skiing 5.2 [95% CI (3.3, 7.0), I^2 = 56.4], biathlon 2.4 [95% CI (0.0, 4.7), I^2 = 77.7], ski jumping 4.8 [95% CI (2.4, 7.2), I^2 = 0.8], and Nordic combined 1.2 [95% CI (0.0, 2.3), I^2 = 0.0] had relatively lower injury rates. The event with the highest injury rate among ice events was bobsleigh, with a 17.1 [95% CI (14.2, 20.0), I^2 = 0.0]. Ice hockey, as one of the few team events in the Olympic Winter Games, also had a relatively high injury rate of 13.0 [95% CI (7.7, 18.4), I^2 = 93.2]. Details can be seen in Figure 2.

Sex-based injuries

Our study reveals a discernable variation in the likelihood of sports injuries among athletes of different sexes participating in various sporting events. It is noteworthy that Nordic combined does not feature a women's event in the Olympic Winter Games, precluding a sex-based injury rate comparison for this event. From the four Olympic Winter Games examined, the injury rate for female athletes was found to be 12.7%, while their male counterparts registered a lower rate at 10.9%. Interestingly, male athletes exhibited higher injury rates than females in sports such as curling, figure skating, short track speed skating, bobsleigh, biathlon, cross-country skiing, and ski jumping. On the contrary, female athletes reported higher injury rates in sports such as hockey, speed skating, luge, skeleton, alpine skiing, freestyle skiing, and snowboarding. Most strikingly, the sex-based differences were particularly pronounced in freestyle skiing, snowboarding and curling. In freestyle skiing, male athletes exhibited an injury rate of 14.7%, contrasted with a substantially higher 22.7% in female athletes – a marked difference of 7.9%. During snowboard events, injury rate was 14.5% for male athletes, and 21.2% for female athletes, representing a difference of 6.7%. Conversely, in curling, male athletes reported an injury rate of 9.0%, while the rate in female athletes was significantly lower at 2.8%, a notable gap of 6.2%. More detailed information can be found in Figure 3.

Injuries to different parts of the body

Injuries among athletes exhibit a pronounced focus on specific body regions, with the knee being most susceptible, accounting for 16.5% of all recorded injuries. This is closely followed by injuries to the thoracic/lumbar/back and wrist/hand/fingers, standing at 10.5% and 10.3% respectively. Collectively, these areas represent 37.3% of all injury occurrences (for a detailed breakdown, please refer to Figure 4). The diversity of sports and their unique characteristics invariably lead to different injury patterns. Mountain Snow Sports and Ice Skating emerged as the sports with the highest incidence of severe injuries. In snow-based sports, apart from thoracic/lumbar/back (10.4%) and head (9.3%) injuries, the knee proved to be the most injury-prone area with a rate of 21.9%. In the realm of ice-skating competitions, following the thigh (15.0%), the knee (13.5%) and the lower leg/Achilles (11.0%) were identified as the most frequently injured sites. An elaborate representation is provided in Figure 5.

Different types of injuries

Throughout the duration of the Olympic Winter Games, the most prevalent injury types are contusions, hematomas, and bruises, collectively representing 17.2% of all injury categories. These are closely followed by strains, inclusive of muscle ruptures, tears, and tendon ruptures (17.1%), and sprains, encompassing dislocations, subluxations, and ligament ruptures (15.4%). More detailed insights are displayed in Figure 6. The distribution of injury types varies with the sport under consideration, as represented in Figure 7. In snow-based sports, sprains (dislocations/subluxations/ligament ruptures) emerge as the most common injury type at 19.5%, succeeded by fractures, which include traumatic/stress/other bone injuries (18.4%), and contusions/hematomas/bruises (17.7%). Conversely, ice skating events witness a preponderance of strains (muscle ruptures/tears/tendon ruptures) at 32.5%, followed by muscle cramps/spasms (17.5%), and contusions/hematomas/bruises (11.5%).

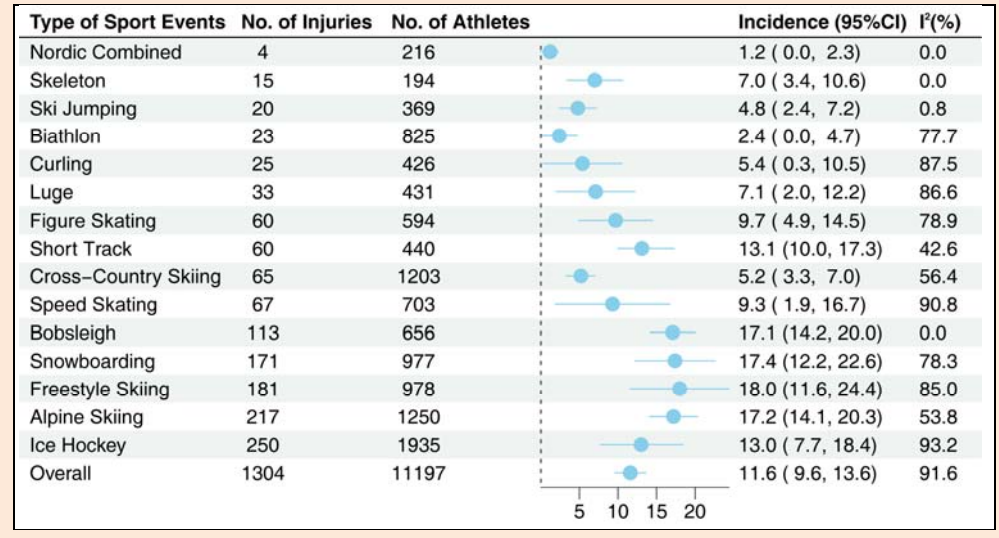

Figure 2. Injury incidence rates across 15 Olympic Winter Sports. I^2 represents the percentage of total variation across studies that is due to heterogeneity rather than chance.

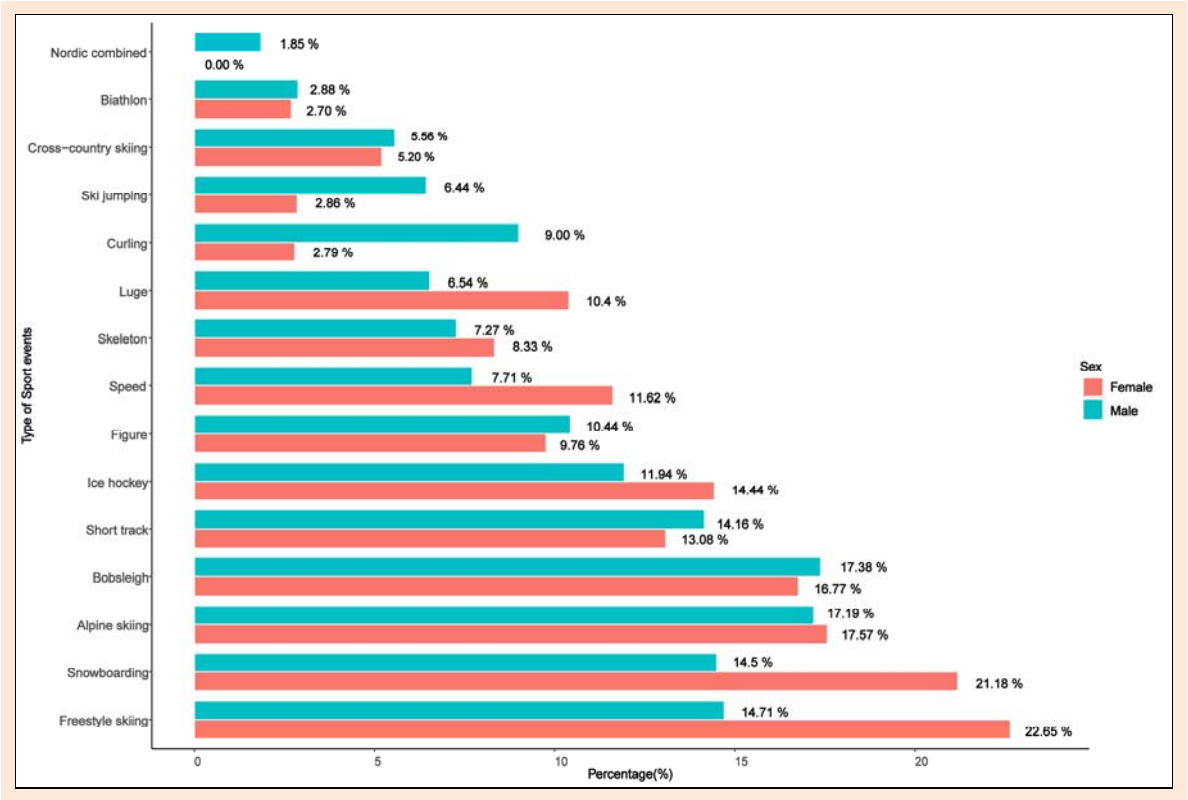

Figure 3. **Sex-based injury incidence rates in 15 Olympic Winter Sports.**

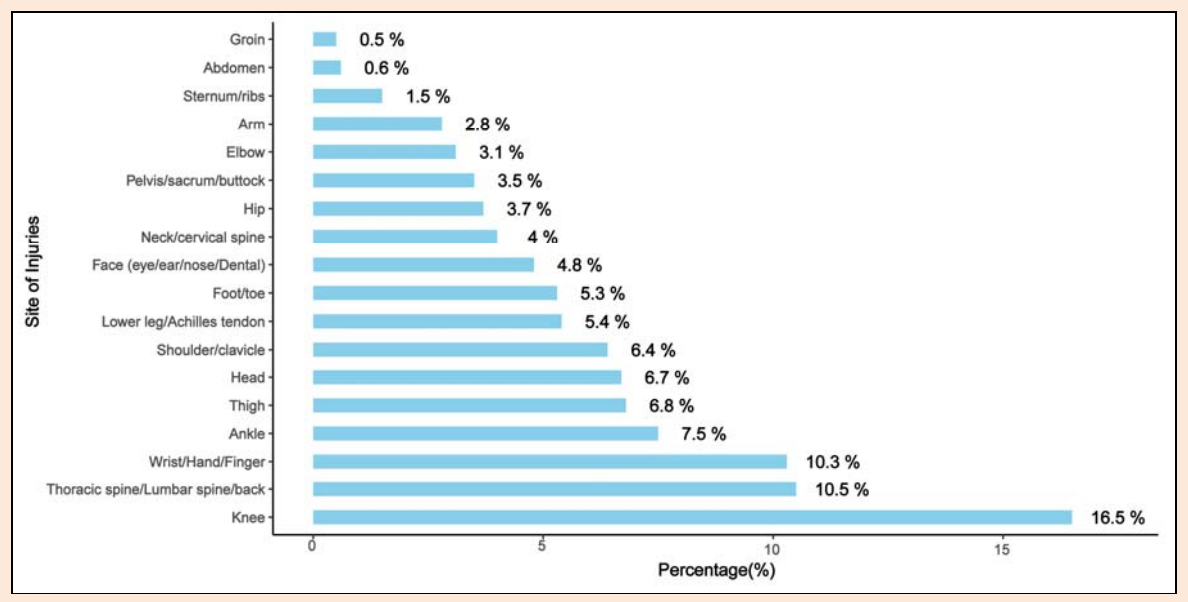

Figure 4. **Distribution of injuries by body part in Olympic Winter Sports.**

Discussion

Objectives and context of Olympic Winter Games injury research

This study meticulously collates and analyses data from the previous four Olympic Winter Games, aiming to shed light on the incidence and fundamental characteristics of injuries suffered by athletes during these highly competitive events. The ambition of this research is twofold. First, it endeavors to facilitate quicker, more precise, and efficient services during the Olympic Games, thereby ensuring that injured athletes receive prompt evaluation and treatment. Secondly, it aims to foster a conducive environment for further exploration into sports injury research. Historically, there has been a paucity of injury surveillance and epidemiological studies on athletes in the context of the Olympic Winter Games, thus limiting the scope for effective comparisons. In 2006, the International Ski Federation launched an injury surveillance system for World Cup athletes, with the objective of documenting injuries and identifying trends over various seasons (Flørenes et al., 2011). Interestingly, when contrasted with the Summer Olympics, which employ an identical injury surveillance system, winter sports events show a markedly higher injury

rate (Soligard et al., 2017; 2022). This observation underscores the elevated risk of injury in winter sports events, particularly those that are conducted outdoors, necessitate high speeds, or involve complex aerial maneuvers.

Overall injury incidence and trends across Olympic Winter Games

In the scope of our research, we collated a total of 1304 sporting injuries from a pool of 11,197 registered athletes, resulting in injury rate of 11.6 [95% CI (9.6, 13.6), I^2 = 91.6]. Significant discrepancies were noted in both injury incidence and the number of injuries across various competitive disciplines in the four Olympic Winter Games examined (Engebretsen et al., 2010). In a broader perspective, snow-based sports exhibited a greater propensity for injuries. Of the fifteen sub-disciplines encompassed by the Olympic Winter Games, the highest injury rates were observed in freestyle skiing, snowboarding, and alpine skiing. However, the ranking changes when we consider the absolute number of injuries, owing to the varying number of participants in different sports; ice hockey, alpine skiing, and freestyle skiing hold the lead. Together, these three sports accounted for 648 injuries, a substantial 49.7% of the total injuries recorded. Importantly, our data highlights a notable observation: female athletes appear to face a heightened risk of injuries compared to their male counterparts. The observed discrepancy in injury rates between genders might be attributed to a confluence of factors. Decouto et al. (2021) postulated that this variation may be linked to an athlete's training experience, psychological factors (e.g., resilience, sense of achievement), and physical fatigue. While the aggregate data suggest a higher incidence of injuries among female athletes, male athletes demonstrate a higher propensity for injuries in specific disciplines such as curling, figure skating, short track speed skating, bobsleigh, biathlon, cross-country skiing, and ski jumping. This underscores the importance of not only analyzing the overarching trends but also delving into individual sports when investigating the relationship between gender and injury rates. The gender differences are particularly pronounced in freestyle skiing, snowboarding, and curling. In freestyle skiing and snowboarding, women might be at an augmented risk when performing certain high-difficulty maneuvers, leading to an elevated susceptibility to injuries during critical movements. Conversely, in curling, the higher injury rate among males could be correlated with their applied force and strategy during gameplay, with male athletes often exhibiting a more aggressive approach, especially when delivering the curling stone. Further specialized studies are imperative to elucidate the underlying mechanisms.

Sport-specific injury risks: High-incidence sports

The International Olympic Committee's Medical Committee has identified ice hockey, speed skating, short-track speed skating, alpine skiing, freestyle skiing, and snowboarding as sports with a high injury risk (Blank et al., 2012). Epidemiological data support this designation, indicating a considerable incidence of serious injuries in alpine skiing, freestyle skiing, and snowboarding when compared to other sports - findings that align with the conclusions of our own research (Weinstein et al., 2019). Furthermore, during the 2016 Winter Youth Olympics, over 65.0% of injuries were recorded in alpine skiing, freestyle skiing, snowboarding, and ice hockey (Steffen et al., 2017). By the 2020 Winter Youth Olympics, snowboarding surfaced as the sport with the highest injury rate at 20.0%, closely followed by freestyle skiing at 14.9%. Combined, injuries in alpine skiing, ice hockey, and snowboarding amounted to 26.3% of the total (Palmer et al., 2021). Thus, within the realm of winter sports, freestyle skiing, snowboarding, alpine skiing, and ice hockey clearly stand out as disciplines with the highest injury incidence.

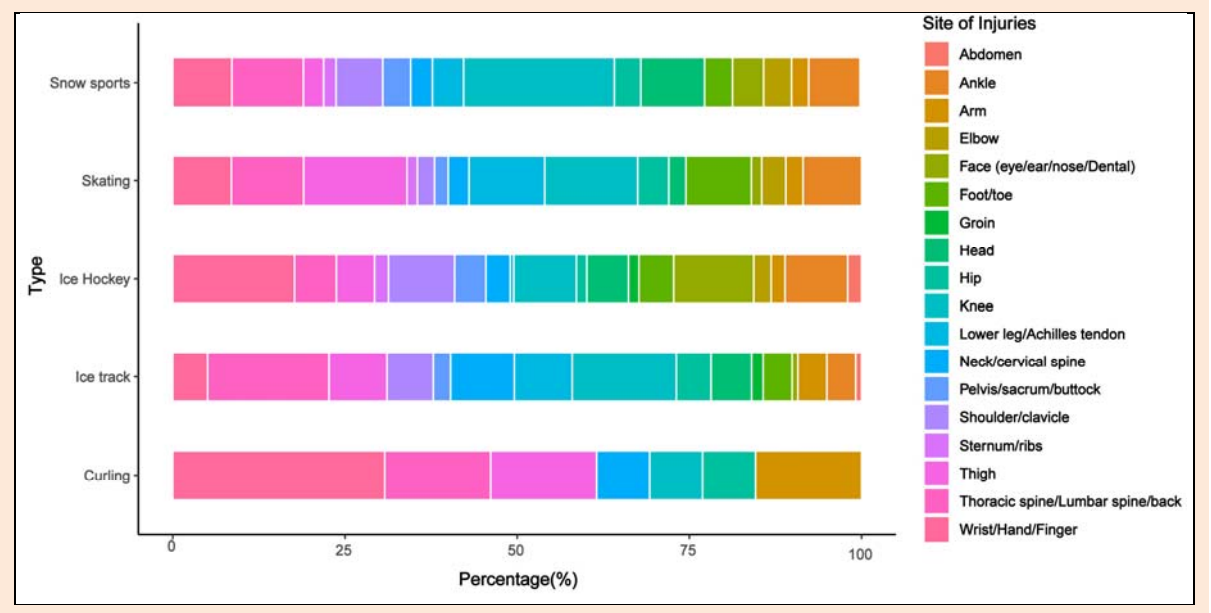

Figure 5. Distribution of injuries by body part across five categories of Olympic Winter Sports. Snow sports: Alpine Skiing; Freestyle Skiing; Snowboarding; Biathlon; Cross-Country Skiing; Nordic Combined; Ski Jumping, Skating: Figure Skating; Short Track; Speed Skating, Ice Hockey: Ice Hockey, Ice track: Bobsleigh; Luge; Skeleton, Curling: Curling.

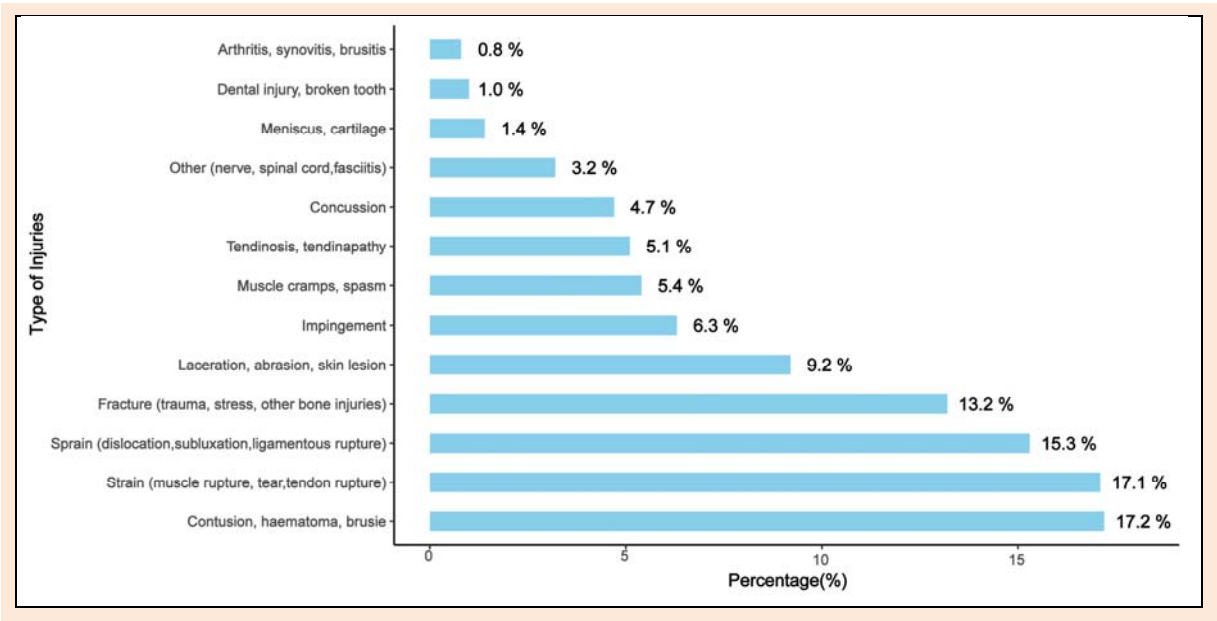

Figure 6. Types of injuries in Olympic Winter Sports.

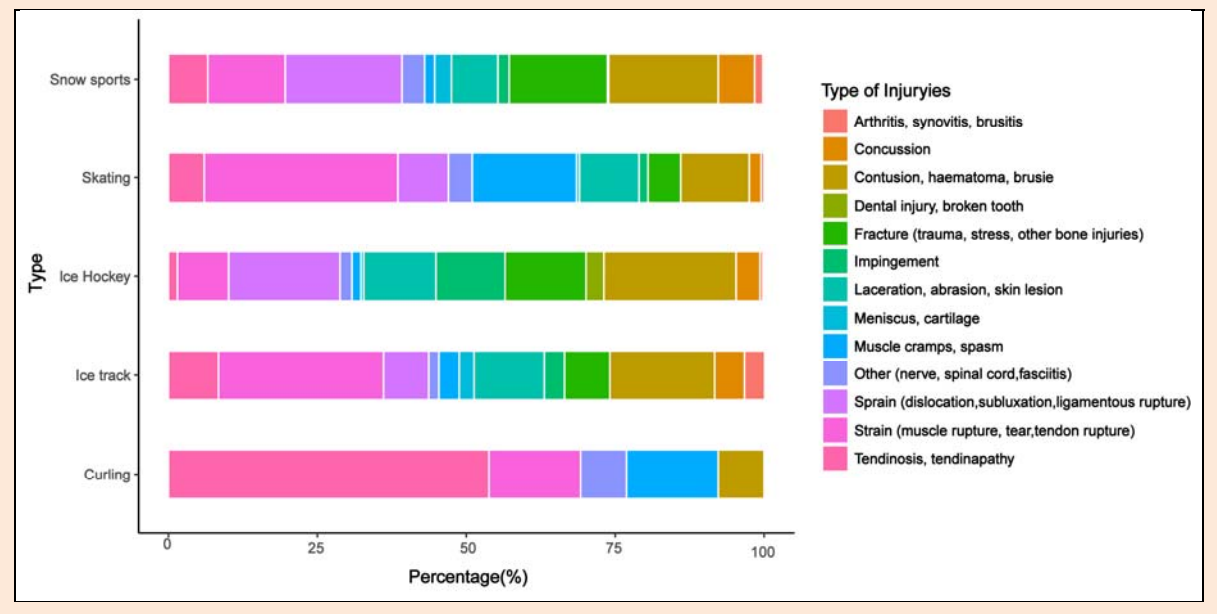

Figure 7. Types of injuries across five categories of Olympic Winter Sports. Snow sports: Alpine Skiing; Freestyle Skiing; Snowboarding; Biathlon; Cross-Country Skiing; Nordic Combined; Ski Jumping, Skating: Figure Skating, Short Track; Speed Skating, Ice Hockey: Ice Hockey, Ice track: Bobsleigh; Luge; Skeleton, Curling: Curling.

Profile of injuries: Common injury locations and types

Given the distinct biomechanical and anatomical characteristics inherent in sports and the human body, certain regions are predisposed to injuries. Data from this study indicates that athletes are most frequently injured in the knee, thoracic/lumbar/spinal regions, and the wrist/hand/fingers, which together account for 37.3% of all injuries. The knee joint, in particular, merits special attention. It often serves a pivotal role in various sports, bearing an athlete's weight, maintaining balance, and facilitating rapid directional shifts. This multifunctionality renders it highly vulnerable to injuries. In the Olympic Winter Games, for sports like skiing and luge, athletes often have to adjust quickly to variations in speed and terrain, substantially elevating the risk of strains or tears in the knee joint (Stenseth et al., 2022). Injuries to the thoracic, lumbar, and spinal regions, especially those linked to winter sports, are frequently associated with abrupt falls. When athletes fall during high-velocity movements, these areas are likely the first to come into contact with the ground, making them prone to impact-related injuries (Major et al., 2014). Injuries to the wrist, hands, and fingers often result from athletes instinctively reaching out to mitigate the impact of a fall. Notably in sports like ice hockey and luge, these areas are susceptible to blows or getting trapped. For winter sports, snow-based sports have a notably higher injury incidence. This can be attributed to the stark differences between snow conditions and fixed or indoor sporting environments, with factors such as snow consistency, slope gradient, temperature, and visibility potentially undergoing significant shifts in a short

span, escalating the risks for athletes (Fudge et al., 2015). Alpine skiing and freestyle skiing, given their high-velocity nature, can lead to particularly severe injuries in the event of operational errors (Major et al., 2014; Soligard et al., 2019). Conversely, curling recorded a relatively low number of injuries, with only 13 cases in total. This likely stems from the sport's low-intensity and speed, eliminating the need for rapid movements or intricate maneuvers, thereby substantially diminishing injury risks, providing a plausible explanation for its lower injury rate (Reeser and Berg, 2004).

The types of injuries athletes most commonly sustain include contusions, hematomas, bruises, strains (comprising muscle tears, ruptures, and tendon injuries), and sprains (encompassing dislocations, subluxations, and ligament tears). Friction and impacts are often responsible for contusions, hematomas, and bruises (Han et al., 2022; Soligard et al., 2019). On snow or ice, the combination of an athlete's equipment, speed, and movements heightens the risks of falls and collisions, particularly with sudden terrain changes or interactions with opponents. Overexertion, improper sporting techniques, or lack of a proper warm-up can lead to strains, with muscle tears and tendon injuries being particularly prevalent in high-intensity sports such as downhill and freestyle skiing (Han et al., 2022). Sprains, mainly involving joints and ligaments, are common during activities like twisting, jumping, and landing, or when an athlete's movement is suddenly hindered (Han et al., 2022).

Injury profiles and risk factors across Olympic Winter Games sports

Winter sports, often characterized by high speeds, high resistance, and intensive metabolic demands, inherently present an elevated risk of athlete injuries during competition. These injuries can have substantial immediate and long-term implications, directly influencing an athlete's competitive performance and overall quality of life. Due to the unique technical maneuvers, sporting environments, and tactical demands of winter sports, the profile of injury locations diverges from those typical in other sports (Pan et al., 2018). The knee, back, and hands emerge as the most susceptible body parts in snow sports, with the predominant types of injuries being abrasions, contusions, fractures, lacerations, and muscle spasms. These injuries often lead to prolonged periods of absence from training and competition, highlighting the crucial need for preventative measures. While most sports injuries are of mild severity, there are instances where athletes suffer from significant, sometimes life-threatening trauma that may impact their long-term recovery and quality of life. During major sports events such as the Olympic Winter Games, even minor injuries and consequent time loss can impede an athlete's participation and performance. Major injuries necessitating extended rest or surgery can lead to withdrawal from competition, curtailment of sports careers, and in severe cases, cause permanent disability or even death. Such outcomes represent a significant loss for the athletes themselves and the countries they represent.

Ice hockey, an Olympic Winter Games sport, is a high-intensity, highly confrontational event marked by rapid movement and robust physical contact. This unique event's nature contributes to the incidence of acute contact injuries, primarily contusions and sprains, which are often localized in unprotected areas such as the hands. Notably, impact-related head injuries are a common occurrence (Anderson et al., 2019). Intriguingly, research indicates that although high ankle sprains are comparatively rare, they are responsible for the lengthiest absences from training and competitions among ice hockey players. Among all types of injuries, collision-associated injuries comprise 69% of those incurred during competition and 38% during training. This discrepancy accounts for why injury rates in ice hockey matches exceed those during training sessions (Flik et al., 2005). Consistent with previous epidemiological findings, ice hockey stands as the sole Olympic Winter Games sport where the majority of injuries occur during competition (Benson et al., 2011; McKay et al., 2014; Mölsä et al., 1997; Pinto et al., 1999; Stuart and Smith, 1995).

Alpine skiing, snowboarding, and freestyle skiing share common event characteristics. Each requires athletes to execute a variety of maneuvers, such as jumps, spins, and turns, on distinct types of snowboards and varied snow tracks. Beyond these three sports, other less contact-intensive and confrontational events are present. Nevertheless, due to their high speed and the technical complexity of the required movements, these athletes are at an elevated risk of losing balance. All these events are conducted outdoors and are markedly influenced by weather conditions such as snow quality, temperature, and wind speed. These factors result in a high incidence rate of contusions and sprains, along with an outsize proportion of severe injuries (Spörri et al., 2017). Research reveals that about 38% of alpine skiing injuries involve the knee joint (Tarka et al., 2019), with no discernible sex differences among elite athletes (Bere et al., 2014). Notably, injury characteristics vary considerably across different snow sports (Fu et al., 2022).

In bobsled competitions, the injury rate is surpassed only by freestyle skiing and snowboarding. The majority of these injuries are acute in nature, involving muscle ruptures, tears, and tendon ruptures triggered by collisions with the track, equipment, and facilities during the push-off and sliding phases (Rizk et al., 2022). This stage is akin to sprinting in summer sports, as it demands athletes to exert full-force sprints, which may precipitate injuries due to vigorous contraction of lower limb muscles, particularly the quadriceps and hamstrings (Malone et al., 2019).

During skating contests, athletes are required to maintain a squatting posture for extended periods, propelling themselves forward repeatedly with the explosive power of their lower limbs (Felser et al., 2016; van der Kruk et al., 2018). This activity often results in overuse injuries (Kowalczyk et al., 2021), with primary injury sites being the thighs, knees, and the thoracic, lumbar, and back regions. Sprains (including dislocations, subluxations, and ligament ruptures), skin tears, and muscle spasms are the most common injury types. Due to the specific variations in skating events, athletes experience diverse injury scenarios. Research demonstrates that joint dislocations and knee contusions due to physical contact, falls, and impacts are the most prevalent injuries during competitions (Quinn et al., 2003). As both the biceps femoris and quadriceps

remain in a state of tense contraction during the skating process, meniscus injuries are relatively infrequent among speed skaters (Okamura et al., 2014; Porter, 2013). Nevertheless, maintaining high tension in lower limb muscles over a lengthy duration may induce muscle spasms, contributing to the high incidence of back pain (Okamura et al., 2014).

In curling contests, athletes are tasked with sliding on the ice and launching the curling stone. This procedure demands athletes to maintain a robust balance and precise strength control. The primary injuries of curling athletes occur during the sliding and throwing phases, chiefly due to falling on the ice from balance loss or exerting excessive force while hurling the curling stone. Injuries among curling athletes are concentrated in the hands, back, and thighs, with tendinitis, strains (muscle ruptures, tears, and tendon ruptures), and muscle spasms being the prevalent injury types. While the injury rate among curling athletes is relatively low, due to the unique nature of curling competitions, any injury incurred can significantly impact an athlete's performance.

Optimizing medical preparedness and injury prevention strategies in Olympic Winter Games

The analysis of Olympic Winter Games sports injury data uncovers significant variances across sporting events, venues, and sexes. These differences demand consideration when providing athletes with medical rescue services. Especially in snow sports and ice hockey events, where the risk of injury is elevated, medical equipment and professional medical staff must be thoroughly prepared. For ice hockey events, attention should be paid to common injuries, such as contusions, sprains, muscle ruptures, tendon ruptures, and fractures. For alpine skiing and snowboarding, focus should be on prevalent injuries, including dislocations, ligament ruptures, and fractures. Moreover, considering the diversity of athletes participating in the Olympic Winter Games, the distribution of male and female medical personnel should be planned based on the unique injury characteristics of different sports and sexes.

In the domain of competitive sports, the features of sports injuries are substantially distinct from typical injuries, necessitating an appropriate adjustment in first aid strategies. First responders require not only vast medical knowledge and experience but also an understanding of specific sporting techniques to furnish athletes with timely and efficacious assistance. As such, professional training for medical personnel should be prioritized, encompassing both first aid instruction and introductions to the rules of competition and the particularities of specific events. This approach ensures that sports injuries incurred during competitions receive prompt and efficient treatment. During this training, the focus should be on elucidating common types of injuries and emergency handling procedures witnessed in the Olympic Winter Games, including bruises, muscle ruptures, and sprains in regions such as the knee, thoracic spine, lumbar spine, back, hand, ankle, thigh, head, shoulder, and clavicle. In the context of sports injuries, the immediacy of first aid measures is of utmost importance, and medical personnel must be equipped to swiftly diagnose and treat injuries.

An in-depth analysis of injuries sustained during the Olympic Winter Games suggests that injury rates among athletes participating in the Olympic Winter Games exceed those of the Summer Olympics (Soligard et al., 2015). This disparity can be primarily attributed to the low-temperature environment in winter, the unique ice and snow conditions of venues, and the nature of contact sports (A competitive sport that requires significant physical contact between participating athletes). A significant risk factor for injuries at the Olympic Winter Games is collisions with fixed objects. For instance, in ice hockey, athletes' sudden accelerations and abrupt stopping actions can cause them to crash out of the rink and collide with the surrounding boards, leading to sport-related injuries. Furthermore, after completing a race, athletes may mentally and physically relax their vigilance, which can lead to unintended collisions with objects. Consequently, it is imperative to amplify protective measures at competition venues. The design of protective facilities for bobsleigh tracks and freestyle skiing tracks should be optimized to enhance athlete safety and minimize potential injury risks. This includes using more shock-absorbent materials, ensuring the protective barriers are of adequate height, and paying particular attention to the placement of protective structures at the track's end to prevent athletes from colliding with hazardous objects.

Strengths and Limitations

In comparison to preceding research, the current study boasts several key advantages. This study provides a thorough and comprehensive exploration of injuries in Olympic Winter Games sports, contributing significant insights and demonstrating notable innovation within this field. With its basis in competition data spanning four Olympic Winter Games, the study offers a sizable sample size and exhaustive data, thereby enhancing the credibility and representativeness of its results. Our analysis encompasses not only the incidence of sports injuries but also the nature, location, and severity of these injuries, providing a comprehensive insight into sports injuries at the Olympic Winter Games. The findings from this study serve as valuable references for the prevention and treatment of Olympic Winter Games sports injuries, offering guidance for medical professionals and a resource for athlete training and competition.

However, this study also has inherent limitations. We cannot definitively evaluate the extent to which the data reflects the actual incidence of injuries or illnesses. This uncertainty might result in misconceptions about the true state of sports injuries, potentially impacting the formulation of preventative and treatment strategies. Additionally, the absence of original data on athlete injuries precludes further interpretation and analysis. Given the four-year cycle of the Olympic Winter Games and the International Olympic Committee's injury monitoring system, there are relatively few studies that meet the inclusion criteria, which might constrain the outcomes of this study. Moreover, since the athletes participating in the Olympic Winter Games primarily comprise top-level athletes from around the globe, the results of this study might not be directly applicable to athletes at other levels.

Conclusion

Athletes in the Olympic Winter Games often face high injury rates, with a diverse spectrum of injury types, including instances of severe injuries. It is noteworthy that freestyle skiing, snowboarding, alpine skiing, bobsleigh, and ice hockey have the highest injury rates among all the sports evaluated. Common injury locations include the knee, thoracic/lumbar spine/back, and wrist, hand, and fingers. Typical injuries comprise contusions, hematomas, bruises, strains (including muscle ruptures, tears, and tendon ruptures), and sprains (such as dislocations, subluxations, and ligament tears).

In light of these findings, we recommend that future research endeavors deeply investigate the mechanisms underlying sports injuries in winter sports and develop predictive models for these injuries. The ultimate goals are to reduce injuries during competition and training and enhance athletes' potential for development and performance breakthroughs. In practical contexts, such as sports training and medical treatment, focus should be given to high-risk events. Rational allocation of medical resources is paramount, along with strengthening targeted training for medical personnel and emphasizing inspection and maintenance of venue facilities. These measures aim to mitigate athletes' injury risk and expedite their recovery and return to competition. Recognizing the limitations of the present study, future research should aim for more comprehensive and in-depth data collection and analysis. This will enable a more precise assessment of injury risk among Olympic Winter Games athletes and facilitate the development of more effective injury prevention and treatment strategies.

Acknowledgements

This study was funded by the National Key R&D Plan "Science and Technology Winter Olympics" Key Special Project (2018YFF0300601), the National Key Research and Development Program Project (2021YFF0306800), the National Natural Science Foundation of China (Grant No. 82202672), and the Heilongjiang Province Basic Research Business Fee Project (2021KYYWF-FC02). The datasets generated and analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study. The authors have no conflict of interest to declare.

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Key points

- Athletes in the Olympic Winter Games often face high injury rates, with a diverse spectrum of injury types, including instances of severe injuries.
- It is noteworthy that freestyle skiing, snowboarding, alpine skiing, bobsleigh, and ice hockey have the highest injury rates among all the sports evaluated.
- Commonly injured areas include the knee, thoracic/lumbar spine/back, and wrist, hand, and fingers. The predominant injuries encountered are contusions, hematomas, strains, and sprains.
- Emphasis on high-risk events is pivotal in sports training and medical care. Tactical allocation of medical resources, enhancement of targeted training for medical personnel, and strict inspection and maintenance of competition venues are paramount to decrease athletes' injury risks.

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