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Injury and illness epidemiology in elite athletes during the Olympic, Youth Olympic and Paralympic Games: a systematic review and meta-analysis

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ABSTRACT

Objective To systematically review and synthesise the incidence and characteristics of injuries and illnesses among athletes participating in the Olympic, Youth Olympic and Paralympic Games.
Design Systematic review and meta-analysis.
Data sources PubMed, Embase, CINAHL, Scopus and Web of Science were searched up to 2 July 2024, and Google Scholar, ClinicalTrials.gov and WHO International Clinical Trials Registry Platform up to 12 December 2023.
Eligibility criteria for selecting studies Cohort studies conducted during the Games reporting injuries and illnesses among athletes. Risk of bias was assessed using the Joanna Briggs Institute critical appraisal tool for prevalence studies, and certainty of evidence using the Grading of Recommendations, Assessment, Development and Evaluation framework.
Results 27 articles were included (10 Olympic, 4 Youth Olympic and 13 Paralympic Games). 23 articles had low, 3 moderate and 1 high risk of bias. Certainty of evidence was high to moderate for Olympic, high to low for Youth Olympic and low for Paralympic Games. Injury incidences per 1000 athlete-days were 6.5 (95% CI 5.9 to 7.2) during Olympic, 10.5 (95% CI 9.4 to 11.8) during Youth Olympic and 14.3 (95% CI 9.9 to 20.7) during Paralympic Games. Illness incidences per 1000 athlete-days were 3.6 (95% CI 2.8 to 4.7), 6.9 (95% CI 6.1 to 7.8) and 9.7 (95% CI 6.5 to 14.4), respectively. Lower limb injuries were frequent during Olympic and Youth Olympic Games, upper limb injuries during Paralympic Games and respiratory illnesses across all Games cohorts.
Conclusions Injury and illness incidences were highest in Paralympic Games, followed by Youth Olympic and Olympic Games. Incidences and patterns of injury and illness were sport and context specific, which could inform future prevention strategies.
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WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Participation in elite sports may be associated with a high risk of injury and illness.
⇒ Injuries and illnesses have a negative impact on athletes' success and are associated with health problems later in life.

WHAT THIS STUDY ADDS

⇒ Incidence of injury and illness is highest during the Paralympic Games, followed by the Youth Olympic and Olympic Games.
⇒ Lower limb injuries have the highest incidence during the Olympic and Youth Olympic Games, and upper limb injuries during the Paralympic Games. Respiratory illness is the most common illness across all three Games cohorts.
⇒ A trend over time towards reduced injury and illness incidence was observed during the Paralympic Games and reduced illness incidence during the Summer Olympic Games. The time trends were less evident during the other Games.
⇒ The findings indicate that female athletes have higher illness incidence than males, and that Youth Olympic athletes have particularly high incidence of concussion and respiratory illness.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study may guide prevention efforts by identifying high-risk athlete groups and sports, and common injury locations, injury types and organ systems affected by illness.
⇒ The findings may inform medical planning for the Olympic, Youth Olympic and Paralympic Games, as well as consistent structured injury and illness surveillance.
⇒ It highlights the need for research on athletes' mental health, impairment-specific data in Paralympic athletes and measures to improve response rate and collection of detailed exposure data in future health surveillance during the Games.

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INTRODUCTION

The Olympic and Paralympic Games are among the most popular sporting events worldwide and a lifetime highlight for many athletes. However, the Games preparation and the Games itself are periods of high physical and psychological demands that may predispose athletes to injury and illness.[1 2] Health problems sustained during the Games may have significant impact on athletes' participation, well-being, performance and long-term health. Previous research has shown that injuries and illnesses negatively impact athletes' success and chances of winning medals.[3–6] Furthermore, career-related injuries are linked to ongoing pain and

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functional limitations among retired Olympians.[7–9] This emphasises the importance of preventing injuries and illnesses to safeguard athletes' health.

Systematic surveillance of injuries and illnesses is a crucial part of athlete health promotion. Such surveillance has been conducted during the Games period for over a decade, but no comprehensive review of the literature on this topic has been performed. A systematic review and meta-analysis provide a structured, transparent and reproducible method to identify, appraise and synthesise the existing literature. By using larger datasets from multiple Games, it allows group comparisons not otherwise possible and provides a better understanding of the injury and illness epidemiology during the Games. This could support healthcare professionals, researchers and governing sports organisations in their efforts to safeguard athletes' health. For instance, identifying common injury and illness types, or athlete subgroups with higher injury or illness incidence, could enable more targeted preventive measures.

The primary objective of this systematic review and meta-analysis was to provide a comprehensive review of the literature on the incidence and characteristics of injuries and illnesses among athletes during the Olympic, Youth Olympic and Paralympic Games. The secondary objective was to analyse the incidence and characteristics among subgroups of athletes based on sex, sports and, for Paralympic athletes, types of impairment.

METHODS

This systematic review and meta-analysis was preregistered in the PROSPERO International Prospective Register of Systematic Reviews (CRD42023475334) and followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses reporting (PRISMA) guideline, as well as the PRISMA-S extension.[10–12]

Eligibility criteria

Eligible studies were original research articles in English, available in full text. We included prospective or retrospective cohort studies conducted during the Olympic, Youth Olympic or Paralympic Games if they reported injuries or illnesses in the Games period. Studies were not eligible if they focused exclusively on injuries or illnesses sustained outside the Games period, specific subtypes of injuries or illnesses or were limited to athletes from single countries, regions or continents. When data overlapped between articles, the article with the most comprehensive data was included.

Information sources

Literature searches were conducted in five electronic databases (PubMed, Embase, CINAHL, Scopus and Web of Science) from database inception to 12 December 2023. Database searches were rerun on 2 July 2024, before final analysis, limited by date from 13 December to 1 July 2024. Grey literature was searched on 12 December 2023 in Google Scholar, ClinicalTrials.gov and the WHO International Clinical Trials Registry Platform (ICTRP). To identify additional unpublished or ongoing studies, we contacted authors of included articles and field experts. Citation tracking of cited and citing references was conducted on 9 February 2024 using the Systematic Review Accelerator SpiderCite tool (https://www.sr-accelerator.com/#/spidercite). We also used citation alerts in Web of Science from 12 February 2024 to 11 June 2024, and weekly email search alerts based on the PubMed search strategy from 5 January 2024 to 10 June 2024.

Search strategy

The search strategy was initially developed for PubMed and adapted for each database and registry. We mapped search terms to database-specific thesaurus (eg, MeSH) where possible, and combined these with synonyms and alternative spellings identified from consensus statements on the reporting of injury, illness and mental health problems.[13–16] No database-provided restrictions or limits were used, and both published and unpublished articles were considered. The search strategy was developed in collaboration between the authors and experienced librarians at Linköping University. Peer review of the PubMed search strategy was conducted by a librarian using the Peer Review of Electronic Search Strategies 2015 Guideline Evidence-Based Checklist.[17] The full search strategy is presented in online supplemental table 1.

Selection process

Search results were imported to the Systematic Review Accelerator Deduplicator tool (https://www.sr-accelerator.com/#/deduplicator) and EndNote, where duplicates were removed.[18 19] The process of screening, including and excluding articles, was conducted using Rayyan.[20] We conducted a pilot screening on 50 articles to test the selection process and calibrate between authors before full screening was initiated. Two authors (KT and KF) independently screened titles and abstracts from the primary search, while one author (KT) screened records from the updated search. Agreement on inclusion or exclusion of articles during the primary screening of titles and abstracts was 99.3%. Full texts of potentially eligible articles were independently assessed for eligibility by the same two authors. Disagreements were resolved through discussion between the two authors, or a third author (MH) if agreement had not been reached. A list of excluded articles is available in online supplemental table 2.

Data collection process

A standardised data extraction form was developed and pilot tested by the authors using three articles, followed by a meeting to refine the form and ensure consistency. Data extraction was then independently conducted in pairs (KT with KF, HL, SS or MH), with equal number of articles per pair. Discrepancies were resolved through discussion between the two authors or a third author (MH or SS) if agreement had not been reached, and general inconsistencies were addressed in a consensus meeting. Missing or unclear data, and raw data if needed, was requested and clarified via email with study authors. Extracted data included general study information, population characteristics and outcome data. A full list of extracted data is available in online supplemental table 3.

Risk of bias assessment

Methodological quality and risk of bias were assessed concurrently with data extraction by the same two authors independently. Disagreements were resolved through discussion between the two authors, or a third author (MH or SS) if agreement had not been reached. General inconsistencies in risk of bias assessments were discussed in a consensus meeting with all involved authors. The Joanna Briggs Institute critical appraisal tool for prevalence studies was used,[21] where nine items are rated as 'yes', 'no', 'unclear' or 'not applicable'. The items evaluate selection bias (items 1–4), coverage bias (item 5), measurement bias (items 6–7), analysis bias (item 8) and non-response bias (item 9). Each 'yes' was assigned a score of one (1), and a summary score was calculated with a maximum score of nine

(9). Articles with a score of 0–4 were considered high risk, 5–6 moderate risk and 7–9 low risk of bias.

Data items

The outcomes were injury and illness (including mental health problems). We collected data on the number of injuries and illnesses, number of participating athletes (an athlete competing at two different Games was counted as two participants), duration (days) of the Games, number of athletes who sustained an injury or illness and incidence data if count data were unavailable. Data on specific injury and illness characteristics were collected when available. Injury and illness characteristics were defined based on the International Olympic Committee (IOC) consensus statement on reporting of data on injury and illness in sports,[13] and reclassified or combined by the authors to ensure consistency across articles.

Outcome measures

The outcome measures were incidence rate, cumulative incidence and injury/illness proportion. Incidence rate was defined as the number of injuries and illnesses per 1000 athlete-days, and cumulative incidence as the number of injuries and illnesses per 100 athletes, with 95% CIs. Injury/illness proportion was defined as the percentage of athletes who sustained an injury or illness in the Games period. If athlete-days were not reported in a study, it was calculated as the total number of participating athletes multiplied by the duration of the Games, assuming all athletes participated the whole Games period.[13] If the duration of the Games or number of athletes was not reported, this information was retrieved from official online sources when possible.

Synthesis methods

Incidence and 95% CIs were calculated using data available in the articles or raw data from study authors. Incidence was calculated for the total population within each of the three cohorts (Olympic, Youth Olympic and Paralympic Games) and, where possible, stratified by (1) sex, (2) Summer and Winter Games, (3) sports, (4) individual and team sports and (5) injury and illness characteristics (injury location, type and severity, and illness organ system and severity). Stratification according to impairment type was not possible since this was not reported in the Paralympic Games articles. Injury/illness proportion was calculated as a mean of proportions from each separate article. Meta-analyses were conducted when data on the number of injuries or illnesses, sample size and exposure from all sports were available. Articles with a high risk of bias were excluded from the meta-analyses to reduce potential bias associated with lower methodological quality.

Random effects Poisson regression models were used,[22–24] with the log incidence exponentiated to reflect incidence per 1000 athlete-days or per 100 athletes. This model was used to account for expected heterogeneity in participant and outcome characteristics across the Games. When meta-analysis was not possible, we synthesised articles narratively. Heterogeneity was assessed using τ^2, Cochran Q test and I^2.[25 26] The τ^2 value quantifies the variance of the true effect sizes across articles,[25] while the Cochran Q test statistically assesses the heterogeneity between articles, and the I^2 describes the percentage of total variation across articles that is due to heterogeneity.[26] An I^2 value between 0% and 40% might not be important, while values of 30%–60% may indicate moderate heterogeneity, 50%–90% substantial heterogeneity and 75%–100% considerable heterogeneity.[27] We explored heterogeneity visually by stratifying results by Olympic, Youth Olympic and Paralympic Games and sex. Pooled incidence rates were summarised in forest plots for the Olympic, Youth Olympic and Paralympic Games, stratified by the total population, females and males. Time trends in incidence rates were described based on visual assessment of forest plots.

Post hoc sensitivity analyses were conducted by including articles with a high risk of bias and for illness incidence by excluding articles covering the 2020 and 2022 Olympic and Paralympic Games to account for the strict hygiene protocols implemented due to the COVID-19 pandemic. Publication bias was not assessed using funnel plots or Egger's test, as initially planned, due to the limited number of articles available.[28] Statistical analyses were conducted in R (V.4.4.1, R Foundation for Statistical Computing, Vienna, Austria) using the 'meta' package.[29]

Certainty assessment

Certainty of evidence was assessed using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) framework.[30 31] Two authors (KT and MH) independently assessed the certainty of evidence for each outcome (injury and illness) separately for the Olympic, Youth Olympic and Paralympic Games, as well as for the total population, females and males. Disagreements were resolved through discussion between the two authors (KT and MH), based on feedback from all authors.

The initial certainty of evidence was rated as 'high', reflecting cohort studies as the most suitable design for these research questions. The certainty of evidence was downgraded based on (1) risk of bias (if most articles had other than low risk of bias), (2) inconsistency (based primarily on visual assessment of forest plots and secondarily on heterogeneity with $I^2 \geq 50\%$), (3) indirectness (if ≥25% of articles did not include appropriate samples or did not use valid and reliable methods for data collection), (4) imprecision (if ≥25% of articles had wide CI or inadequate sample sizes) or (5) publication bias (if suspected).

Equity, diversity and inclusion statement

Our author group includes mixed genders (five women, seven men), nationalities, ages, medical professions and both senior and junior researchers. The systematic review included articles on both female and male athletes, youth athletes and athletes with disabilities.

RESULTS

Study selection

A total of 20 587 records were identified from databases and registers, and 10 947 duplicate records were removed. We screened 9640 records based on title and abstract, excluding 9574 as not relevant. Full-text screening was conducted on 66 articles, of which 40 were excluded. An additional 2193 records were identified through other methods, resulting in inclusion of one additional article. In total, 27 articles were included (figure 1).[32–58]

Characteristics of included articles

Among the 27 articles, 10 reported data from the Olympic,[32–41] 4 from the Youth Olympic[42–45] and 13 from the Paralympic Games.[46–58] Characteristics of all articles are presented in online supplemental table 4.

Olympic Games

Six articles were from the Summer Olympic Games[32–34 36 38 40] and four from the Winter Olympic Games.[35 37 39 41] A total of 58

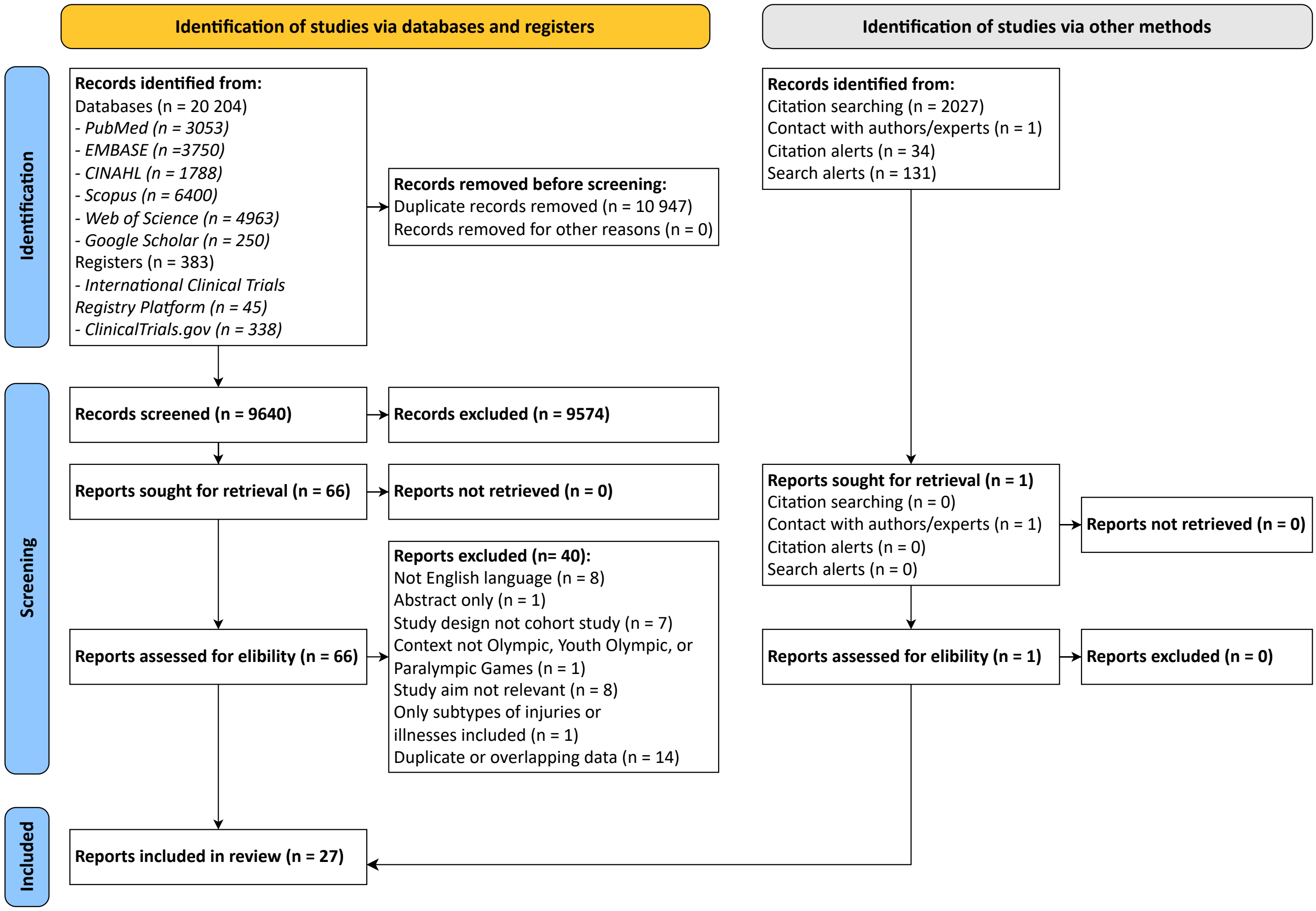

Figure 1 PRISMA 2020 flow diagram. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

141 participants were included (female 25 701; male 32 440). All articles included both females and males, seven reported both injury and illness data,[35–41] and three reported injury data only.[32–34] Eight articles reported data from all sports,[34–41] one from football[32] and one from team sports.[33]

Youth Olympic Games

One article was from the Summer Youth Olympic Games[44] and three from the Winter Youth Olympic Games.[42 43 45] A total of 7871 participants were included (female 3813; male 4052; sex missing for 6 athletes). All articles reported data from both females and males, injuries and illnesses, and all sports.

Paralympic Games

Six articles were from three Summer Paralympic Games[48 49 52 53 56 57] and seven articles from four Winter Paralympic Games.[46 47 50 51 54 55 58] A total of 14 224 participants were included (female 5073; male 9151). All articles reported data from both females and males, and from all sports. Seven articles reported data on injuries only,[46 47 49 50 52 55 57] five reported illnesses only[48 51 53 54 56] and one reported both injuries and illnesses.[58]

Risk of bias in articles

23 articles were assessed to have low risk,[32–45 48–51 54–58] 3 moderate risk[47 52 53] and 1 high risk of bias (table 1).[46] Limitations mainly involved response rate and participant/study descriptions. 24 articles had limitations related to response rate (due to low response rate or uncertainty about the completeness of injury and illness reporting), and 13 articles had limitations related to participant and study descriptions (due to insufficient information on impairment among Paralympic athletes).

Injury incidence and characteristics

We present the main results on injury incidence rate for the total population, females and males (figure 2), injury location, injury type and sports with the highest incidence (figure 3). Detailed results and additional subgroup analyses are presented in online supplemental table 5–7.

Olympic Games

The pooled injury incidence from the Olympic Games included data from eight articles (5895 injuries, 55 243 athletes, 930 934 athlete-days).[34–41] The incidence rate was 6.5 (95% CI 5.9 to 7.2) per 1000 athlete-days (figure 2), cumulative incidence 11.1 (95% CI 9.9 to 12.3) per 100 athletes, and the mean injury proportion 10.3%. Incidence rate was similar in females (6.7 (95% CI 5.9 to 7.6)) and males (6.0 (95% CI 5.5 to 6.6)). The incidence rate of lower limb injuries (3.1 (95% CI 2.7 to 3.4)) was higher than upper limb (1.4 (95% CI 1.3 to 1.6)) and trunk injuries (1.0 (95% CI 0.8 to 1.1)). Joint sprains (1.3 (95% CI 1.1 to 1.6)), contusions (1.3 (95% CI 1.0 to 1.6)) and muscle/tendon (1.1 (95% CI 0.9 to 1.3)) were the injury types with the highest incidence rate.

Two articles were not included in the meta-analysis due to differences in data collection and the inclusion of only football or

Table 1 Risk of bias assessment of included articles

Article	1	2	3	4	5	6	7	8	9	Overall score (0–9)	Risk of bias
Junge *et al*[32]	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	Low
Junge *et al*[33]	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	Low
Junge *et al*[34]	Y	Y	Y	Y	Y	Y	Y	Y	N	8	Low
Engebretsen *et al*[35]	Y	Y	Y	Y	Y	Y	Y	Y	U	8	Low
Engebretsen *et al*[36]	Y	Y	Y	Y	Y	Y	Y	Y	U	8	Low
Soligard *et al*[37]	Y	Y	Y	Y	Y	Y	Y	Y	U	8	Low
Soligard *et al*[38]	Y	Y	Y	Y	Y	Y	Y	Y	N	8	Low
Soligard *et al*[39]	Y	Y	Y	Y	Y	Y	Y	Y	N	8	Low
Soligard *et al*[40]	Y	Y	Y	Y	Y	Y	Y	Y	N	8	Low
Soligard *et al*[41]	Y	Y	Y	Y	Y	Y	Y	Y	N	8	Low
Ruedl *et al*[42]	Y	Y	Y	Y	Y	Y	Y	Y	U	8	Low
Steffen *et al*[43]	Y	Y	Y	Y	Y	Y	Y	Y	Y	9	Low
Steffen *et al*[44]	Y	Y	Y	Y	Y	Y	Y	Y	N	8	Low
Palmer *et al*[45]	Y	Y	Y	Y	Y	Y	Y	Y	U	8	Low
Webborn *et al*[46]	Y	Y	N	U	U	U	U	N	U	2	High
Webborn *et al*[47]	Y	Y	Y	U	U	Y	Y	U	U	5	Moderate
Schwellnus *et al*[48]	Y	Y	Y	U	Y	Y	Y	Y	U	7	Low
Willick *et al*[49]	Y	Y	Y	U	Y	Y	Y	Y	U	7	Low
Derman *et al*[50]	Y	Y	Y	U	Y	Y	Y	Y	U	7	Low
Derman *et al*[51]	Y	Y	Y	U	Y	Y	Y	Y	U	7	Low
Derman *et al*[52]	Y	N	Y	U	Y	Y	Y	Y	U	6	Moderate
Derman *et al*[53]	Y	N	Y	U	Y	Y	Y	Y	U	6	Moderate
Derman *et al*[54]	Y	Y	Y	U	Y	Y	Y	Y	U	7	Low
Derman *et al*[55]	Y	Y	Y	U	Y	Y	Y	Y	U	7	Low
Derman *et al*[56]	Y	Y	Y	U	Y	Y	Y	Y	U	7	Low
Derman *et al*[57]	Y	Y	Y	U	Y	Y	Y	Y	U	7	Low
Derman *et al*[58]	Y	Y	Y	U	Y	Y	Y	Y	U	7	Low
Total 'yes' score	27	25	26	14	25	26	26	25	3		

(1) Was the sample frame appropriate to address the target population? (2) Were study participants sampled in an appropriate way? (3) Was the sample size adequate? (4) Were the study subjects and the setting described in detail? (5) Was the data analysis conducted with sufficient coverage of the identified sample? (6) Were valid methods used for the identification of the condition? (7) Was the condition measured in a standard, reliable way for all participants? (8) Was there appropriate statistical analysis? (9) Was the response rate adequate, and if not, was the low response rate managed appropriately?
N, no; U, unclear; Y, yes.

team sports.[32 33] One article reported injury in football (matches only), with a rate of 2.1 injuries per match for females and 3.7 for males (overall and 95% CI not reported).[32] One article reported injury in team sports (matches only), with an overall rate of 0.8 injuries (95% CI 0.8 to 0.9) per match.[33]

Youth Olympic Games

The pooled injury incidence from the Youth Olympic Games included data from four articles (1066 injuries, 7871 athletes, 97 794 athlete-days).[42–45] The incidence rate was 10.5 (95% CI 9.4 to 11.8) per 1000 athlete-days (figure 2), cumulative incidence 12.3 (95% CI 10.3 to 14.6) per 100 athletes, and the mean injury proportion 11.4%. Incidence rate was similar in females (11.2 (95% CI 10.2 to 12.1)) and males (9.8 (95% CI 7.7 to 12.4)). The incidence rate of lower limb injuries (4.6 (95% CI 3.6 to 5.8)) was higher than upper limb (2.8 (95% CI 2.5 to 3.1) and trunk injuries (1.5 (95% CI 1.0 to 2.4)). Contusions (2.2 (95% CI 1.4 to 3.3)), muscle/tendon (2.0 (95% CI 1.2 to 3.2)) and joint sprains (1.8 (95% CI 1.3 to 2.6)) had the highest incidence rate.

Paralympic Games

The pooled injury incidence from the Paralympic Games included data from seven articles (2060 injuries, 13 808 athletes, 192 903 athlete-days).[47 49 50 52 55 57 58] One article was not included due to high risk of bias.[46] The incidence rate was 14.3 (95% CI 9.9 to 20.7) per 1000 athlete-days (figure 2), cumulative incidence 18.2 (95% CI 13.6 to 24.4) per 100 athletes and the mean injury proportion 15.9%. Incidence rate was similar in females (14.9 (95% CI 10.0 to 22.2)) and males (13.9 (95% CI 9.7 to 20.1)). The regions with the highest incidence rate were the upper limb (4.5 (95% CI 3.0 to 6.7)), lower limb (4.2 (95% CI 2.9 to 6.2)) and trunk (1.6 (95% CI 0.9 to 2.6)).

Time trends in injury incidence

A decreasing trend in injury incidence rates was observed up to the 2022 Paralympic Games, whereas the time trend was less evident for the Olympic and Youth Olympic Games (figure 2).

Illness incidence and characteristics

We present the main results on illness incidence rate for the total population, females and males (figure 4), affected organ systems and sports with the highest incidence (figure 3). Detailed results and additional subgroup analyses are presented in online supplemental table 8–10.

Olympic Games

The pooled illness incidence from the Olympic Games included data from seven articles (2631 illnesses, 44 266 athletes, 755

Article	City	Year	Summer/Winter	Injuries	Athletes	Incidence (95% CI)
Olympic Games: Total						
Junge et al. 2009	Beijing	2008	Summer	1055	10977	6.01 (5.65–6.38)
Engebretsen et al. 2013	London	2012	Summer	1361	10568	7.58 (7.18–7.99)
Soligard et al. 2017	Rio de Janeiro	2016	Summer	1101	11274	5.74 (5.41–6.09)
Soligard et al. 2023	Tokyo	2020	Summer	1035	11315	5.38 (5.06–5.72)
Engebretsen et al. 2010	Vancouver	2010	Winter	287	2567	6.58 (5.84–7.38)
Soligard et al. 2015	Sochi	2014	Winter	391	2780	7.81 (7.06–8.63)
Soligard et al. 2019	Pyeongchang	2018	Winter	376	2914	7.59 (6.84–8.40)
Soligard et al. 2024	Beijing	2022	Winter	289	2848	5.97 (5.30–6.70)
Overall						**6.50 (5.91–7.15)**
Heterogeneity: $I^2 = 93.9\%$, $\tau^2 = 0.0168$, $p < 0.0001$						
Olympic Games: Female						
Junge et al. 2009	Beijing	2008	Summer	464	4654	6.23 (5.68–6.82)
Engebretsen et al. 2013	London	2012	Summer	621	4676	7.81 (7.21–8.45)
Soligard et al. 2017	Rio de Janeiro	2016	Summer	471	5089	5.44 (4.96–5.96)
Soligard et al. 2023	Tokyo	2020	Summer	467	5423	5.07 (4.62–5.55)
Engebretsen et al. 2010	Vancouver	2010	Winter	137	1045	7.71 (6.47–9.12)
Soligard et al. 2015	Sochi	2014	Winter	168	1121	8.33 (7.11–9.68)
Soligard et al. 2019	Pyeongchang	2018	Winter	169	1210	8.22 (7.02–9.55)
Soligard et al. 2024	Beijing	2022	Winter	128	1276	5.90 (4.92–7.02)
Overall						**6.67 (5.86–7.60)**
Heterogeneity: $I^2 = 92.3\%$, $\tau^2 = 0.0308$, $p < 0.0001$						
Olympic Games: Male						
Junge et al. 2009	Beijing	2008	Summer	549	6323	5.43 (4.98–5.90)
Engebretsen et al. 2013	London	2012	Summer	712	5892	7.11 (6.60–7.65)
Soligard et al. 2017	Rio de Janeiro	2016	Summer	581	6185	5.53 (5.09–5.99)
Soligard et al. 2023	Tokyo	2020	Summer	568	5892	5.67 (5.21–6.16)
Engebretsen et al. 2010	Vancouver	2010	Winter	142	1522	5.49 (4.62–6.47)
Soligard et al. 2015	Sochi	2014	Winter	219	1659	7.33 (6.39–8.37)
Soligard et al. 2019	Pyeongchang	2018	Winter	207	1704	7.15 (6.21–8.19)
Soligard et al. 2024	Beijing	2022	Winter	136	1572	5.09 (4.27–6.02)
Overall						**6.04 (5.50–6.64)**
Heterogeneity: $I^2 = 86.4\%$, $\tau^2 = 0.0149$, $p < 0.0001$						
Youth Olympic Games: Total						
Steffen et al. 2020	Buenos Aires	2018	Summer	619	3984	11.95 (11.03–12.93)
Ruedl et al. 2012	Innsbruck	2012	Winter	111	1021	10.87 (8.94–13.09)
Steffen et al. 2017	Lillehammer	2016	Winter	108	1083	9.97 (8.18–12.04)
Palmer et al. 2021	Lausanne	2020	Winter	228	1783	9.13 (7.99–10.40)
Overall						**10.52 (9.36–11.82)**
Heterogeneity: $I^2 = 77.3\%$, $\tau^2 = 0.0086$, $p = 0.0042$						
Youth Olympic Games: Female						
Steffen et al. 2020	Buenos Aires	2018	Summer	297	1981	11.53 (10.26–12.92)
Ruedl et al. 2012	Innsbruck	2012	Winter	45	461	9.76 (7.12–13.06)
Steffen et al. 2017	Lillehammer	2016	Winter	56	502	11.16 (8.43–14.49)
Palmer et al. 2021	Lausanne	2020	Winter	132	869	10.85 (9.08–12.87)
Overall						**11.15 (10.24–12.14)**
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.7453$						
Youth Olympic Games: Male						
Steffen et al. 2020	Buenos Aires	2018	Summer	322	2003	12.37 (11.05–13.79)
Ruedl et al. 2012	Innsbruck	2012	Winter	65	554	11.73 (9.06–14.95)
Steffen et al. 2017	Lillehammer	2016	Winter	52	581	8.95 (6.68–11.74)
Palmer et al. 2021	Lausanne	2020	Winter	89	914	6.96 (5.59–8.56)
Overall						**9.79 (7.73–12.39)**
Heterogeneity: $I^2 = 88.2\%$, $\tau^2 = 0.0461$, $p < 0.0001$						
Paralympic Games: Total						
Willick et al. 2013	London	2012	Summer	633	3565	12.68 (11.71–13.71)
Derman et al. 2018a	Rio de Janeiro	2016	Summer	510	3657	9.96 (9.12–10.86)
Derman et al. 2023b	Tokyo	2020	Summer	386	4403	5.84 (5.28–6.46)
Webborn et al. 2012	Vancouver	2010	Winter	120	505	23.76 (19.70–28.41)
Derman et al. 2016a	Sochi	2014	Winter	174	547	26.51 (22.72–30.75)
Derman et al. 2020	Pyeongchang	2018	Winter	142	567	20.87 (17.58–24.60)
Derman et al. 2024	Beijing	2022	Winter	95	564	12.96 (10.48–15.84)
Overall						**14.27 (9.86–20.65)**
Heterogeneity: $I^2 = 98.6\%$, $\tau^2 = 0.2438$, $p < 0.0001$						
Paralympic Games: Female						
Willick et al. 2013	London	2012	Summer	196	1218	11.49 (9.94–13.22)
Derman et al. 2018a	Rio de Janeiro	2016	Summer	208	1389	10.70 (9.29–12.25)
Derman et al. 2023b	Tokyo	2020	Summer	158	1853	5.68 (4.83–6.64)
Webborn et al. 2012	Vancouver	2010	Winter	33	124	26.61 (18.32–37.37)
Derman et al. 2016a	Sochi	2014	Winter	40	129	25.84 (18.46–35.19)
Derman et al. 2020	Pyeongchang	2018	Winter	39	134	24.25 (17.25–33.16)
Derman et al. 2024	Beijing	2022	Winter	30	138	16.72 (11.28–23.87)
Overall						**14.88 (9.99–22.15)**
Heterogeneity: $I^2 = 96.1\%$, $\tau^2 = 0.2691$, $p < 0.0001$						
Paralympic Games: Male						
Willick et al. 2013	London	2012	Summer	437	2347	13.30 (12.08–14.61)
Derman et al. 2018a	Rio de Janeiro	2016	Summer	302	2268	9.51 (8.47–10.65)
Derman et al. 2023b	Tokyo	2020	Summer	228	2550	5.96 (5.21–6.79)
Webborn et al. 2012	Vancouver	2010	Winter	87	381	22.83 (18.29–28.17)
Derman et al. 2016a	Sochi	2014	Winter	134	418	26.71 (22.38–31.64)
Derman et al. 2020	Pyeongchang	2018	Winter	103	433	19.82 (16.18–24.04)
Derman et al. 2024	Beijing	2022	Winter	65	426	11.74 (9.06–14.96)
Overall						**13.93 (9.67–20.06)**
Heterogeneity: $I^2 = 97.9\%$, $\tau^2 = 0.2351$, $p < 0.0001$						

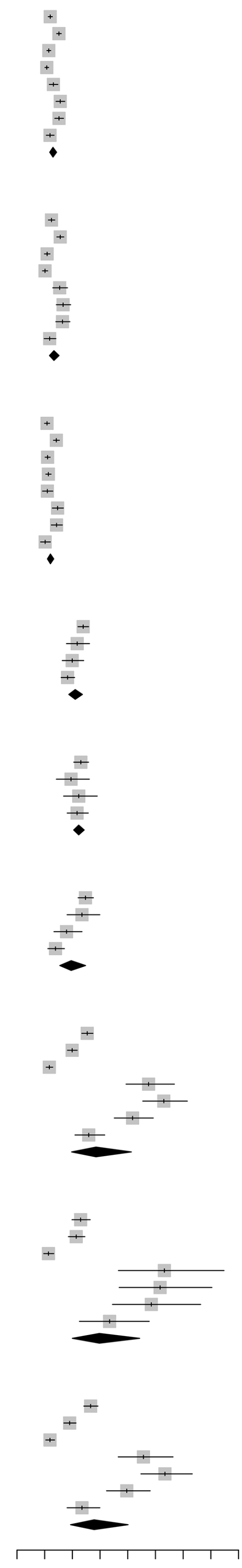

Figure 2 Forest plot of pooled injury incidence rate per 1000 athlete-days (95% CI) for total, female and male, by the Olympic, Youth Olympic and Paralympic Games. Pooled overall injury incidence rates in bold text.

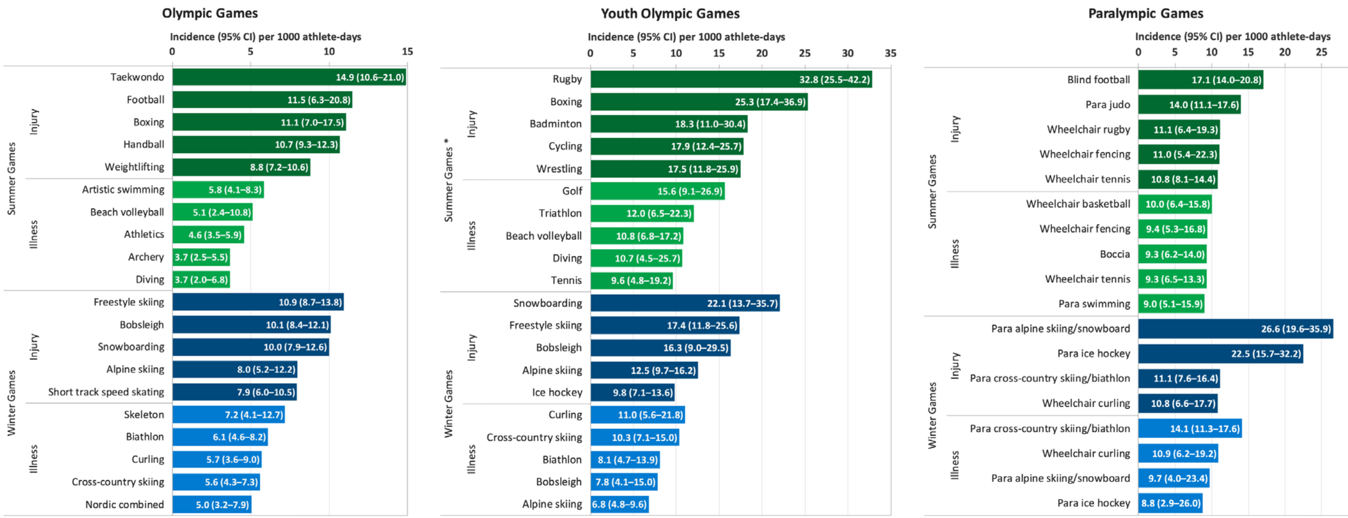

Figure 3 Pooled injury and illness incidence rate per 1000 athlete-days (95% CI) for the five summer and winter sports with the highest incidence, by the Olympic, Youth Olympic and Paralympic Games. Only sports with data from three or more articles are included (skateboarding (Olympic Games, injury and illness), karate (Olympic Games, injury and illness), Para taekwondo (Paralympic Games, injury) and sailing (Paralympic Games, illness) are excluded due to insufficient data). *For the Summer Youth Olympic Games, incidence is based on only one article (tennis, break dancing and karate had the same illness incidence, with only tennis displayed in the figure).

302 athlete-days).[35–41] The incidence rate was 3.6 (95% CI 2.8 to 4.7) per 1000 athlete-days (figure 4), cumulative incidence 6.2 (95% CI 4.8 to 8.0) per 100 athletes and the mean illness proportion 6.0%. Females had a slightly higher incidence rate than males (4.3 (95% CI 3.3 to 5.6) vs 2.8 (95% CI 2.2 to 3.6)). Respiratory illness (1.7 (95% CI 1.0 to 2.8)) had higher incidence rate than gastrointestinal (0.6 (95% CI 0.4 to 0.7) and dermatological illness (0.3 (95% CI 0.2 to 0.4).

Youth Olympic Games

The pooled illness incidence from the Youth Olympic Games included data from four articles (668 illnesses, 7871 athletes, 97 794 athlete-days).[42–45] The incidence rate was 6.9 (95% CI 6.1 to 7.8) per 1000 athlete-days (figure 4), cumulative incidence 8.5 (95% CI 7.9 to 9.2) per 100 athletes, and the mean illness proportion 8.1%. Females had a higher incidence rate than males (8.5 (95% CI 7.3 to 10.0) vs 5.3 (95% CI 4.7 to 6.0)). Respiratory illness (4.5 (95% CI 3.5 to 5.7)) had higher incidence rate than gastrointestinal (1.0 (95% CI 0.6 to 1.5)) and other or not specified illnesses (0.6 (95% CI 0.4 to 1.1).

Paralympic Games

The pooled illness incidence from the Paralympic Games included data from 6 articles (1703 illnesses, 13 303 athletes, 187 853 athlete-days).[48 51 53 54 56 58] The incidence rate was 9.7 (95% CI 6.5 to 14.4) per 1000 athlete-days (figure 4), cumulative incidence 12.9 (95% CI 9.0 to 18.4) per 100 athletes, and the mean illness proportion 11.8%. Incidence rate was similar in females (10.8 (95% CI 7.5 to 15.5)) and males (9.0 (95% CI 5.9 to 13.9)). The respiratory (2.6 (95% CI 1.5 to 4.5)), dermatological (1.7 (95% CI 1.3 to 2.3) and gastrointestinal (1.3 (95% CI 0.9 to 1.9) organ systems had the highest incidence rate.

Time trends in illness incidence

Illness incidence rates showed a decreasing trend during the Summer Olympic and both Summer and Winter Paralympic Games, whereas the time trend was less evident for the Winter Olympic and Youth Olympic Games (figure 4).

Sensitivity analyses

The sensitivity analysis that included one article with a high risk of bias[46] (applicable to Paralympic Games injury data) resulted in a lower overall incidence rate of 12.6 (95% CI 8.4 to 18.8) per 1000 athlete-days. Sensitivity analyses excluding data from the 2020 and 2022 Olympic and Paralympic Games[40 41 56 58] resulted in slightly higher illness incidence rates, with overall rates of 4.4 (95% CI 3.7 to 5.2) for the Olympic Games and 13.2 (95% CI 10.6 to 16.4) for the Paralympic Games, respiratory illness rates of 2.4 (95% CI 1.8 to 3.3) for the Olympic Games and 3.8 (95% CI 3.1 to 4.7) for the Paralympic Games.

Certainty of evidence

Certainty of evidence ranged from high to low across assessed outcomes and groups (online supplemental table 11). Certainty of evidence was high to moderate for the Olympic, high to low for the Youth Olympic and low for the Paralympic Games. The main reasons to downgrade the certainty of evidence were inconsistency (due to variability in incidence estimates and statistical heterogeneity) and imprecision (due to wide CIs).

DISCUSSION

Our meta-analyses highlight variations in injury and illness incidence across the three cohorts, with the highest incidence consistently observed during the Paralympic Games, followed by the Youth Olympic and Olympic Games. Paralympic athletes had an injury and illness incidence rate of 14.3 and 9.7, Youth Olympic athletes 10.5 and 6.9, and Olympic athletes 6.5 and 3.6 per 1000 athlete-days, respectively. Subgroup analyses indicated that injury incidence was similar between sexes across all three Games cohorts, whereas illness incidence was highest in females. This is the first systematic review and meta-analysis on injury and illness incidence during the Olympic, Youth Olympic and Paralympic Games, and our findings offer a novel contribution and insights for healthcare professionals, researchers, Olympic and Paralympic committees and governing sports organisations to prioritise medical support and prevention efforts for the protection of athletes' health.

Article	City	Year	Summer/Winter	Illnesses	Athletes	Incidence (95% CI)
Olympic Games: Total						
Engebretsen et al. 2013	London	2012	Summer	758	10568	4.22 (3.92–4.53)
Soligard et al. 2017	Rio de Janeiro	2016	Summer	613	11274	3.20 (2.95–3.46)
Soligard et al. 2023	Tokyo	2020	Summer	438	11315	2.28 (2.07–2.50)
Engebretsen et al. 2010	Vancouver	2010	Winter	185	2567	4.24 (3.65–4.90)
Soligard et al. 2015	Sochi	2014	Winter	249	2780	4.98 (4.38–5.63)
Soligard et al. 2019	Pyeongchang	2018	Winter	279	2914	5.63 (4.99–6.33)
Soligard et al. 2024	Beijing	2022	Winter	109	2848	2.25 (1.85–2.72)
Overall						**3.62 (2.83–4.65)**
Heterogeneity: $I^2 = 97.4\%$, $\tau^2 = 0.1090$, $p < 0.0001$						
Olympic Games: Female						
Engebretsen et al. 2013	London	2012	Summer	402	4676	5.06 (4.57–5.58)
Soligard et al. 2017	Rio de Janeiro	2016	Summer	289	5089	3.34 (2.97–3.75)
Soligard et al. 2023	Tokyo	2020	Summer	248	5423	2.69 (2.37–3.05)
Engebretsen et al. 2010	Vancouver	2010	Winter	88	1045	4.95 (3.97–6.10)
Soligard et al. 2015	Sochi	2014	Winter	123	1121	6.10 (5.07–7.27)
Soligard et al. 2019	Pyeongchang	2018	Winter	146	1210	7.10 (5.99–8.35)
Soligard et al. 2024	Beijing	2022	Winter	59	1276	2.72 (2.07–3.51)
Overall						**4.28 (3.28–5.58)**
Heterogeneity: $I^2 = 96\%$, $\tau^2 = 0.1218$, $p < 0.0001$						
Olympic Games: Male						
Engebretsen et al. 2013	London	2012	Summer	314	5892	3.13 (2.80–3.50)
Soligard et al. 2017	Rio de Janeiro	2016	Summer	250	6185	2.38 (2.09–2.69)
Soligard et al. 2023	Tokyo	2020	Summer	190	5892	1.90 (1.64–2.19)
Engebretsen et al. 2010	Vancouver	2010	Winter	78	1522	3.01 (2.38–3.76)
Soligard et al. 2015	Sochi	2014	Winter	121	1659	4.05 (3.36–4.84)
Soligard et al. 2019	Pyeongchang	2018	Winter	133	1704	4.59 (3.84–5.44)
Soligard et al. 2024	Beijing	2022	Winter	46	1572	1.72 (1.26–2.30)
Overall						**2.81 (2.19–3.60)**
Heterogeneity: $I^2 = 94\%$, $\tau^2 = 0.1041$, $p < 0.0001$						
Youth Olympic Games: Total						
Steffen et al. 2020	Buenos Aires	2018	Summer	334	3984	6.45 (5.78–7.18)
Ruedl et al. 2012	Innsbruck	2012	Winter	86	1021	8.42 (6.74–10.40)
Steffen et al. 2017	Lillehammer	2016	Winter	81	1083	7.48 (5.94–9.30)
Palmer et al. 2021	Lausanne	2020	Winter	167	1783	6.69 (5.71–7.79)
Overall						**6.88 (6.10–7.76)**
Heterogeneity: $I^2 = 46.5\%$, $\tau^2 = 0.0010$, $p = 0.1322$						
Youth Olympic Games: Female						
Steffen et al. 2020	Buenos Aires	2018	Summer	199	1981	7.73 (6.69–8.88)
Ruedl et al. 2012	Innsbruck	2012	Winter	52	461	11.28 (8.42–14.79)
Steffen et al. 2017	Lillehammer	2016	Winter	47	502	9.36 (6.88–12.45)
Palmer et al. 2021	Lausanne	2020	Winter	97	869	7.97 (6.47–9.73)
Overall						**8.50 (7.25–9.95)**
Heterogeneity: $I^2 = 55.3\%$, $\tau^2 = 0.0049$, $p = 0.0814$						
Youth Olympic Games: Male						
Steffen et al. 2020	Buenos Aires	2018	Summer	135	2003	5.18 (4.35–6.14)
Ruedl et al. 2012	Innsbruck	2012	Winter	34	554	6.14 (4.25–8.58)
Steffen et al. 2017	Lillehammer	2016	Winter	34	581	5.85 (4.05–8.18)
Palmer et al. 2021	Lausanne	2020	Winter	64	914	5.00 (3.85–6.39)
Overall						**5.32 (4.72–6.00)**
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.7208$						
Paralympic Games: Total						
Schwellnus et al. 2013	London	2012	Summer	657	3565	13.16 (12.18–14.21)
Derman et al. 2018b	Rio de Janeiro	2016	Summer	511	3657	9.98 (9.13–10.88)
Derman et al. 2023a	Tokyo	2020	Summer	280	4403	4.24 (3.76–4.77)
Derman et al. 2016b	Sochi	2014	Winter	123	547	18.74 (15.57–22.36)
Derman et al. 2019	Pyeongchang	2018	Winter	87	567	12.79 (10.24–15.77)
Derman et al. 2024	Beijing	2022	Winter	45	564	6.14 (4.48–8.21)
Overall						**9.66 (6.47–14.42)**
Heterogeneity: $I^2 = 98.4\%$, $\tau^2 = 0.2430$, $p < 0.0001$						
Paralympic Games: Female						
Schwellnus et al. 2013	London	2012	Summer	245	1218	14.37 (12.62–16.28)
Derman et al. 2018b	Rio de Janeiro	2016	Summer	216	1389	11.11 (9.68–12.69)
Derman et al. 2023a	Tokyo	2020	Summer	138	1853	4.96 (4.17–5.87)
Derman et al. 2016b	Sochi	2014	Winter	28	129	18.09 (12.02–26.14)
Derman et al. 2019	Pyeongchang	2018	Winter	25	134	15.55 (10.06–22.95)
Derman et al. 2024	Beijing	2022	Winter	14	138	7.80 (4.27–13.09)
Overall						**10.79 (7.50–15.52)**
Heterogeneity: $I^2 = 95.7\%$, $\tau^2 = 0.1814$, $p < 0.0001$						
Paralympic Games: Male						
Schwellnus et al. 2013	London	2012	Summer	412	2347	12.54 (11.36–13.81)
Derman et al. 2018b	Rio de Janeiro	2016	Summer	295	2268	9.29 (8.26–10.41)
Derman et al. 2023a	Tokyo	2020	Summer	142	2550	3.71 (3.13–4.38)
Derman et al. 2016b	Sochi	2014	Winter	95	418	18.94 (15.32–23.15)
Derman et al. 2019	Pyeongchang	2018	Winter	62	433	11.93 (9.15–15.30)
Derman et al. 2024	Beijing	2022	Winter	31	426	5.60 (3.80–7.95)
Overall						**9.03 (5.85–13.94)**
Heterogeneity: $I^2 = 97.7\%$, $\tau^2 = 0.2824$, $p < 0.0001$						

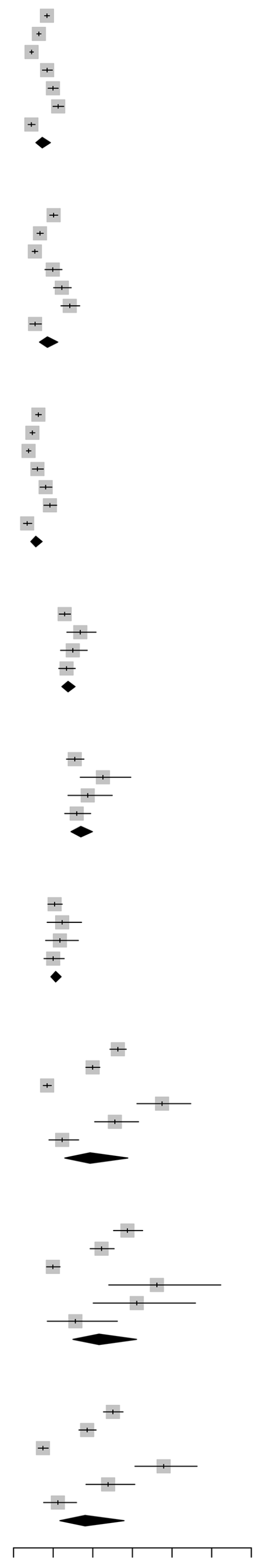

Figure 4 Forest plot of pooled illness incidence rate per 1000 athlete-days (95% CI) for total, female and male, by the Olympic, Youth Olympic and Paralympic Games. Pooled overall illness incidence rates in bold text.

High injury incidence in the Youth Olympic and Paralympic Games

While direct comparisons between the cohorts are challenging, for example, due to variations in data collection and analyses across studies, our findings suggest that Youth Olympic athletes are more susceptible to injury than Olympic athletes during the Games. This concurs with a recent study of Swedish Olympic athletes that found higher incidence in athletes ≤20 years old, with rates decreasing with higher age.[59] The reasons behind this are not certain but may reflect a combination of factors such as maturation status, high physiological and psychosocial strain, limited experience and inadequate load management and recovery.[60 61]

A concern is that Paralympic athletes, already living with a disability, report a high incidence of injury. There is still a lack of large prospective studies on Para athletes outside the Games period, but existing studies report that injuries are a significant burden in this population.[62–65] Injury rates also vary depending on impairment type, where athletes with visual impairment or neuromuscular disorders experience the highest incidence and athletes with brain disorders the lowest incidence.[66] In addition to the underlying impairment, factors related to other comorbidities, the use of assistive devices and limited multidisciplinary medical support may also contribute to the high risk in this population.[62] Challenges with an accessible environment, long transportations and lack of recovery due to tighter competition schedules are important additional factors to consider.

Injury incidence and characteristics: subgroup comparisons

Injury incidence was similar between females and males across all three Games cohorts. This aligns with studies outside the Games period on Swedish Olympic and Paralympic athletes.[59 62] In contrast, higher weekly injury prevalence was observed for female Norwegian Olympic athletes[67] and male Norwegian Paralympic athletes.[63] A previous systematic review and meta-analysis reported higher incidence among male team sport athletes compared with females,[68] but in the present study, we did not specifically analyse sex differences in team sports. Small sex differences were observed in various sports, but such comparisons are less robust due to the small number of injuries and athletes in many sports. These inconsistent findings highlight the need for further research into sex differences across various sports and the importance of considering the specific context.

When comparing the Summer and Winter Games, we found similar injury incidence during the Olympic Games, while during the Youth Olympic Games, the Summer Games showed slightly higher incidence. Data from the Summer Youth Olympic Games include only one article and comparisons should be interpreted with caution. In contrast, injury incidence during the Winter Paralympic Games was more than double that of the Summer Paralympic Games. Sports with the highest incidence in all three Games cohorts—such as taekwondo, freestyle skiing, rugby, snowboarding, blind football and Para alpine skiing/snowboarding—are characterised by frequent contact with other athletes or the ground, high speeds and large forces. These factors are likely to contribute to the increased incidence, and there is a need to further assess injury mechanisms and potential prevention measures in these sports. Furthermore, injury mechanism (acute/repetitive) and onset (sudden/gradual) were reported inconsistently across the articles, and this should be standardised in future studies to provide healthcare professionals with clinically meaningful data.

Lower limb injuries had the highest incidence during the Olympic and Youth Olympic Games, whereas both upper and lower limb injuries were common during the Paralympic Games, consistent with previous studies.[59 62 63 65 67 69] Notably, the concussion incidence estimate was four times higher during the Youth Olympic Games than the Olympic Games and should be a high priority for health protection measures.

High illness incidence in the Youth Olympic and Paralympic Games

Illness incidence was higher during the Youth Olympic and Paralympic Games compared with the Olympic Games, with respiratory illnesses having the highest incidence across all three cohorts, as observed in previous studies.[63 65 67 69] The respiratory illness incidence estimate during the Youth Olympic Games was approximately 2.7 times higher than the Olympic Games and 1.7 times higher than the Paralympic Games (1.9 and 1.2 times higher, respectively, when excluding the 2020 and 2022 Games data). Higher training loads, international travel, training during the winter and competition periods increase the risk of respiratory illness,[70] and youth athletes may be particularly susceptible due to limited experience in managing travel, recovery and intense competition. Even though the differences between the Games cohorts were less pronounced when data from the 2020 and 2022 Olympic and Paralympic Games held during the COVID-19 pandemic were excluded, these findings may indicate that infection hygiene protocols may be less strict during the Youth Olympic Games. Further research is needed to understand whether the observed differences reflect true variation between the cohorts or are influenced by contextual factors (eg, three out of four Youth Olympic Games were held during winter).

Similarly, Para athletes face unique challenges, including underlying impairments and comorbidities such as impaired lung and bladder function that may increase their susceptibility to illness. The relatively high rate of dermatological illness among Paralympic athletes may be attributed to sensory loss or the use of wheelchairs or prostheses, increasing the risk of skin infections. Research conducted outside the Games period among Norwegian Olympic and Paralympic athletes shows higher illness prevalence among Paralympic athletes,[63 67] whereas similar illness incidence was observed among UK Olympic and Paralympic athletes.[65 69] These contrasting findings highlight the importance of considering the specific context such as the Games and non-Games periods.

Illness incidence and characteristics: subgroup comparisons

The incidence of illness was consistently higher in females than males across all three cohorts, and the difference was most evident during the Youth Olympic Games. When analysing sports with three or more articles available, the highest incidence among female athletes was observed in curling, skeleton and biathlon during the Olympic Games; and cross-country skiing, biathlon and luge during the Youth Olympic Games. Among male athletes, the highest incidence was observed in cross-country skiing, biathlon and Nordic combined during the Olympic Games; and curling, bobsleigh and Nordic combined during the Youth Olympic Games. While females had higher incidence in some sports and males in others, comparisons are difficult due to often overlapping confidence intervals. These findings suggest that sex differences in illness incidence are context and sport specific.

Like previous studies from outside the Games period,[63 67] we observed slightly higher incidence estimates during the Winter

Games than the Summer Games across all three cohorts, although with overlapping CIs. These differences may be attributed to increased exposure to respiratory pathogens during winter, cold air, increased training load in certain winter sports or seasonal patterns in respiratory illness.[70 71]

Time trends in injury and illness incidence

Interestingly, we observed a trend over time towards reduced injury incidence during the Summer and Winter Paralympic Games, while the trend was less evident during the Olympic and Youth Olympic Games. It is unclear whether this trend reflects actual reductions in injury rates or can be attributed to other factors, such as differences in reporting, variations in sport programmes, better medical support, contextual differences between the Games, or impact from the COVID-19 pandemic during the 2020 and 2022 Games. Further research is needed to understand the underlying reasons and to follow long-term time trends.

Likewise, up to 2022, a decreasing trend of illness incidence was evident during the recent Summer Olympic and Summer and Winter Paralympic Games. The low illness incidence during the 2020 and 2022 Olympic and Paralympic Games could likely be due to the strict illness countermeasures implemented during these Games because of the COVID-19 pandemic. It remains to be seen whether lessons were learnt from the 2020 and 2022 Games regarding countermeasures and strategies to reduce illness risk, or whether illness incidence increased again during the 2024 Olympic and Paralympic Games. That is, to find an acceptable level of risk and balance between strict restrictions associated with lower illness incidence and looser restrictions that may result in higher incidence.

Strengths and limitations

The main strengths of this study are the extensive literature search, thorough method for screening, risk of bias assessment and certainty of evidence assessment using the GRADE framework.

Our study also has limitations that need to be considered. We calculated incidence based on athlete-days, assuming all athletes participated the whole duration of the Games.[13] This approach likely overestimates the number of athlete-days and underestimates the injury and illness incidence. Although consistent injury and illness definitions were used across articles, the medical attention definition used may have led to underreporting of less severe health problems and mental health problems. Additionally, under-reporting in certain groups of athletes may exist due to the potential consequences of reporting health problems, such as impact on selection. Response rates for National Olympic Committees reporting of injuries and illnesses were low in several articles, particularly among smaller countries, which may underestimate the true injury and illness incidence. These countries may not have their own medical staff and are dependent on the Organising Committee medical staff, which may contribute to under-reporting compared with larger countries. We acknowledge that reporting of new (incidence) and/or pre-existing health problems (prevalence) is challenging in epidemiological studies. Methods for injury and illness surveillance have improved over the last two decades with two recent consensus documents from the International Olympic and Paralympic Committee,[13 14] which will facilitate more consistent and coherent reporting in the future.

For the Paralympic Games, we initially planned to analyse the injury and illness incidence based on impairment type, but this was not possible since impairment of athletes without injury and illness was not reported in the articles. This has subsequently been analysed for the 2012 and 2016 Summer Paralympic Games.[66] For the Youth Olympic Games, data were mainly from the Winter Games, with only one article from the Summer Games. Additional studies from the Summer Games are needed to obtain more robust estimates for the Youth Olympic Games overall. Data on severity (ie, time loss) were estimated at the time of reporting an injury or illness. Although more detailed and validated information would enhance understanding of time loss due to injury and illness during the Games, we recognise that collecting such data in this setting may be challenging.

Considerable heterogeneity measured by I^2 in several of our meta-analyses indicates that a large proportion of the variability in incidence is due to heterogeneity rather than chance, for example, due to season, climate, Games location, sport programmes and participants. Large articles with narrow CI may also have contributed to this,[72] though the τ^2 value indicates that the variance in true incidence might not be that large in many analyses. However, the small number of included articles may have led to less stable τ^2 values. Publication bias was not formally assessed since too few articles were available,[28] but given the comprehensive search strategy used, we believe that all relevant articles were captured.

Certainty of evidence

Certainty of evidence ranged from high to low and was downgraded due to inconsistency and/or imprecision. For the Olympic Games, certainty of evidence was high to moderate, while for the Youth Olympic Games, it was high to low. For the Paralympic Games, certainty of evidence was consistently low for all outcomes and analyses. This likely reflects the heterogeneous population at the Paralympic Games, where differences in impairments, classifications and sports contribute to greater variability in estimates and wider CIs. The lower certainty of evidence should be considered when interpreting the pooled incidence rate estimates and suggests that future studies may influence and refine these estimates.

Implications for practice, policy and future research

This study provides important data on injury and illness epidemiology to inform future prevention efforts during the Games. Injury and illness incidences were higher during the Youth Olympic and Paralympic Games compared with the Olympic Games, highlighting the need to explore why these populations are at greater risk. For instance, this may include exploring the potential impact of limited experience managing travel, recovery and intense competition among youth athletes and the management of underlying impairments and comorbidities in Paralympic athletes to reduce their susceptibility to injury and illness. Additionally, ensuring adequate medical support during the preparation for the Games is essential. Prevention efforts should prioritise lower limb injuries, particularly knee, ankle/foot and thigh injuries, in Olympic and Youth Olympic athletes, and both upper and lower limb injuries in Paralympic athletes. The high incidence of concussion in Youth Olympic athletes warrants further attention, for example, by identifying high-risk sports and common concussion mechanisms in these sports, and suitable preventive measures (eg, education, rules/regulations, technique/skill training). There is evidence of a preventive effect of exercise-based training interventions for acute and overuse sport injuries,[73] but their effectiveness in the elite athlete population, and during the condensed periods of the Games, is less certain. Prevention interventions are likely most valuable in the build-up period before the Games, while during the Games, focus on management and avoiding exacerbations of existing conditions is key to reducing impact on athlete performance and health. Illness prevention needs particular attention in female athletes, and for respiratory illnesses specifically during the Youth Olympic Games, for example, by implementing strict hygiene protocols.

Our findings may guide National Olympic and Paralympic Committee medical teams and organising committee medical staff in the planning of medical services during the Games. Efforts are needed to improve response rates and coverage, particularly for smaller countries, and to expand injury and illness reporting forms into more languages to enhance inclusivity. More research from the Summer Youth Olympic Games is also needed. To ensure more robust and accurate incidence estimates, we advocate for the collection of individual-level impairment data for Paralympic athletes and detailed exposure data from all athletes. Finally, athlete mental health during the Games is an under-researched area, and existing studies have not addressed mental health issues specifically. A recent IOC consensus statement recommends the implementation of mental health surveillance,[16] which has been employed at the 2024 Games and is planned for future Games.

CONCLUSIONS

This systematic review and meta-analysis is the first to comprehensively synthesise the literature on injury and illness during the Olympic, Youth Olympic and Paralympic Games. The incidence of injury and illness varied across the three Games cohorts, where Paralympic athletes had an injury and illness incidence rate of 14.3 and 9.7, Youth Olympic athletes 10.5 and 6.9, and Olympic athletes 6.5 and 3.6 per 1000 athlete-days, respectively. Subgroup analyses indicated that across all three Games cohorts, injury incidence was similar between sexes, while illness incidence was highest in females. Certainty of evidence for injury and illness incidence estimates varied, with high to moderate for the Olympic Games, high to low for the Youth Olympic Games, and low for the Paralympic Games. These findings provide insights to guide medical support and prevention strategies to safeguard athletes' health during the Games.

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