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Review

Epidemiology and associated injury risk factors in figure skating: A systematic review

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ABSTRACT

Objectives: To identify and critically appraise the available evidence on injury epidemiology and risk factors in figure skating.
Design: Systematic review.
Methods: Eight electronic databases were searched from inception to 01 November 2023. Studies were included if they reported injury epidemiology and/or injury risk factors in figure skating. Non-English publications were excluded. Risk of Bias of included studies was assessed using the QUIPS tool (quality in prognostic factor studies).
Results: This systematic review identified twenty-nine studies (n = 4202 figure skaters), with an injury prevalence of 2.1 %–34 %. An injury incidence of 1.37 injuries/1000 total training hours was reported in one study (n = 8). Three significant intrinsic risk factors (older age, previous history of stress fracture and a higher body mass) and eight significant extrinsic risk factors (training more than 12 sessions per week, skipping meals, RED-s indicators, hamstring and quadriceps immobility, training rather than competing, increased time on-ice time and boot-foot length difference) were identified from individual studies. Age, as the most studied risk factor, requires careful interpretation due to study design limitations.
Limitations: Existing data lacks quality of evidence and current reported injury risk factors in figure skating should be interpreted with caution.
Conclusions: High-quality research of injuries and injury risk factors in figure skating is scarce. The inconsistent reporting of injury data across the currently available literature due to variations in injury definition and data collection methods makes it difficult to compare and draw conclusions. A critical need exists for standardized research approaches to accurately determine the true burden of injury in this sport.

Practical implications

This systematic literature review identifies:

- The injury prevalence ranges between 2.1 % and 34 %. However, we predict that these values may underestimate the burden of injury due to the data collection methods and injury definitions used.
- Three intrinsic and eight extrinsic injury risk factors were statistically significant. The modifiable nature of many of these factors highlights the importance of the development of targeted prevention strategies, which should be integrated into training and rehabilitation programs to reduce injury risk in figure skaters.
- Current literature presents varying definitions of injury. Future research should align injury definitions, recording and reporting with the 2020 IOC consensus statement[1] to facilitate data pooling and more accurate comparison.
- A notable gap exists in the literature regarding the epidemiology of injury and risk factors specific to male figure skaters. The role of a male figure skater largely differs from that of a female figure skater in disciplines such as pairs and ice dancing. Addressing this gap is essential for developing tailored injury prevention strategies and ensuring gender-specific insights in future research.

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1. Introduction

Figure skating is an artistic sport requiring physical strength, agility, power, and grace. While physical activity offers well-documented health benefits for children and adolescents,[2] the risk and prevalence of injury in figure skating should be considered. Compared to other similar artistic sports such as ballet (1.24 injuries per 1000 dance hours) figure skating (1.37 per 1000 h of training) may have a marginally higher injury incidence.[3]

Figure skating is governed by the International Skating Union (ISU) and comprises four disciplines; single skating, pair skating, ice dancing and synchronized skating.[4] The sport's global popularity has grown[5] along with the technical demands placed on athletes.[6] A major change in the technical demands of the sport occurred in 1990 when compulsory figures were eliminated allowing more focus on a wide variety of jumps. Another major change occurred in 2006 when a new judging system was introduced. Considering the escalated technical demand, the increased popularity of the sport and the high training loads, the number of figure skaters presenting with injuries is predicted to increase.[7] Unfortunately, research on figure skating injuries has not developed at the same pace, resulting in limited knowledge of the injury epidemiology and associated injury risk factors among these athletes.[8] While previous research and narrative reviews on figure skating injuries have been published,[5,7,9–11] a systematic review has not been conducted to date. A limitation of these studies is that they did not follow a predefined systematic search strategy, which may have resulted in bias. Further, none of these studies commented on the methodological rigor of the included studies. Completing a systematic review on the epidemiology of figure skating injuries and associated injury risk factors is therefore crucial for several reasons. First, this review will collate all relevant studies addressing our research questions, ensuring a comprehensive understanding of the current evidence while minimizing bias. This approach will provide researchers with a concise overview of existing findings, helping to identify critical gaps in the figure skating literature that require further investigation. Second, by assessing the methodological rigor of the included studies through a risk of bias assessment, we can offer valuable insights into the trustworthiness and quality of the existing figure skating research. This is particularly important for clinicians and healthcare professionals in sport and exercise medicine, who rely on accurate and robust data to guide their practice when treating figure skaters. Additionally, it will help direct future research efforts toward areas most needing improvement, such as developing targeted injury prevention programs and implementing early interventions for high-burden injuries.

Injury prevention is well outlined by Van Mechelen's injury prevention framework.[12] Summarizing the existing evidence on the epidemiology of injury and the injury risk factors in figure skating will help identify the extent of the injury problem and inform the development of effective injury risk management strategies.

The primary aim of this systematic review is to systematically identify, review, summarize and critically appraise all the currently available literature regarding the epidemiology of injury. The secondary aim of this review is to systematically identify, review, summarize and critically appraise all the currently available literature regarding the associated injury risk factors in figure skating.

2. Methods

2.1. Protocol registration

We followed the 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines,[13] led by the PERSiST guidelines for implementing PRISMA in exercise, rehabilitation, sport medicine and sport science.[14] Our protocol for this systematic review was registered on PROSPERO (CRD42021293641) before the search was conducted.

2.2. Eligibility criteria

2.2.1. Inclusion criteria

All quantitative studies which aimed to investigate the epidemiology of injury (incidence, prevalence, clinical characteristics) and/or injury risk factors among figure skaters during training or competition were eligible for selection. Studies reporting the epidemiology of injury or injury risk factors during figure skating competition had to clearly state that the study participants were figure skaters or that they participated in a figure skating competition. To ensure that all participants in the included studies were figure skaters, we initially considered whether the competitions were ISU-sanctioned. However, this criterion was ultimately unnecessary, as all studies explicitly stated that their participants were either figure skaters or involved in one of the four recognized figure skating disciplines. Only original research studies were included. All injury definitions were considered for inclusion (clinical assessment, medical encounters, self-reported injuries). Injury risk factors from univariate and multivariate analyses were included. No limiters to publication date were applied.

2.2.2. Exclusion criteria

We excluded the following study designs: opinion-based papers, reports, case series, conference proceedings, commentaries, and studies only investigating biomarkers of potential injury. Studies not published in the English language were excluded.

2.3. Information source and search strategy

Eight electronic databases were searched for relevant studies; Ovid MEDLINE, PubMed, Scopus, SPORTDiscus, CINAHL, Health Source Nursing/Academic, Cochrane Library and MEDLINE EBSCO. The search strategy was developed by the lead author (NS) under the supervision of a Medical Librarian (SS) and senior co-author (CV) (Online Supplementary Appendix 1). The initial search was conducted by the lead author (NS) under the guidance of a senior co-author (PhD) (CV) who has extensive experience in conducting systematic and living systematic reviews. The search was conducted from inception to 28 April 2023 and was updated by the lead author (NS) on 01 November 2023. Two sets of keywords were developed to address our research aims. The first set of keywords focused on various definitions for figure skating ("pair skat*", "single skat*", "ice danc*", "synchronized skat*", "synchronised skat*", "figure skat*", "ice skat*"). The second set focused on words used to describe the epidemiology of injury and injury risk factors (injur*, epidemiolog*, prevalence*, incidence*, health*, "medical encounter*", "risk factor*", "protective factor*", "medical problem*"). The first set of keywords was combined with an OR operator followed by the second set of keywords. Thereafter, an AND operator was used to combine the first set of keywords with the second set of keywords. The final results were limited to studies published in English. To ensure all potentially relevant studies were included, one reviewer (NS) screened the reference lists of all included studies.

2.4. Study selection

The identified studies were imported to EndNote 20 to identify and remove duplicates. The lead author and the senior co-author (NS & CV) independently screened the titles and abstracts for potential eligibility. Two reviewers (NS & CV) independently screened the selected full texts for eligibility. Any discrepancies in selection between the two reviewers were resolved *via* discussion until consensus was reached. The Cohen's Kappa inter-rater agreement was tested prior to consensus.

2.5. Data collection process and data items

2.5.1. Main outcome variables

In this review, we grouped and reported the outcome variables in line with the 2020 International Olympic Committee (IOC) consensus

statement where possible.[1] No assumptions were made in this review, and the data were reported as presented in each study. The main outcome variables reported are the incidence of injury (rate: per 1000 h of figure skating, per 1000 figure skaters; proportion: % of new injuries among the population), injury prevalence (% of injured figure skaters), injury severity (time loss), frequency of injury (n, %) for the anatomical region, body area, tissue and pathology type, and statistically significant injury risk factors (odds ratio, prevalence ratio, risk ratio, risk difference p-values, correlation coefficients *etc.*).

2.5.2. Data Extraction

The final included studies were all allocated a number from 1 to 29. The studies were then randomly allocated to four authors (MB, CV, AJVR & DG) by dividing the studies into multiples of four. Data extraction was completed using a standardized data extraction sheet (Online Supplementary Appendix 2). One researcher (NS) extracted data from all included studies for quality control.

The standardized data extraction sheet included information on the following:

- Publication and study details: year of publication, author initials and surnames, study design, data collection procedure, study setting, number of participants, follow-up period and injury definition.
- Participant demographics: age (years), sex (male/female), training age, level of participation and body mass index (BMI, kg/m^2).
- Epidemiology of injury: incidence of injury (rate: injuries/1000 figure skaters or injuries/1000 h of figure skating; proportion: % of new injuries among the population), prevalence (% of injured participants) and clinical characteristic of injury (frequency of injured anatomical region, body area, tissue type, pathology type and injury severity).
- Injury risk factors: using univariate or multivariate analysis, risk factors and/or protective factors.

The demographics extracted were chosen to provide the reader with the context of the participants of the included studies. BMI was specifically extracted, as being light in weight and having a low fat percentage has been proven beneficial for athletic performance required in figure skating.[15] However, a recent consensus statement on relative energy deficiency in dance reported that culture of esthetics, under-fueling and skipping meals contributed to the risk factors.[16]

2.6. Study risk of bias

Risk of bias (RoB) was assessed using the QUIPS tool (quality in prognostic factor studies).[17] Beforehand, a meeting was held between NS and MS to discuss each domain and signaling item of the QUIPS tool to ensure inter-rater reliability. NS and MS further optimized the tool for studies that did not report prognostic factors or follow a prospective study design with a follow-up period before use. MS has previous experience in completing risk of bias assessments. MS trained NS before a pilot was completed. The RoB was assessed independently per domain and ranked as either high or a low RoB. If a study scored 75 % or more "yes" responses to the signaling items of a domain, then the study's domain was ranked as low RoB. Scores of <75 % "yes" responses were deemed as a high RoB for that domain. Two authors (NS & MS) independently assessed the RoB of each included study. Discrepancies were resolved through consensus meeting between NS and MS. The inter-rater reliability was tested before the consensus meetings.

2.7. Data synthesis and analysis

Due to the heterogeneous nature of the data from all included studies a descriptive narrative synthesis systematic review including quantitative data was conducted. Data analyses were performed by reporting the epidemiology of injury and associated injury risk factors in figure skating. Data were reported in two main categories: training *vs* competition injuries. Where possible, data were subdivided into various disciplines within figure skating. The risk factors were reported under two main categories: intrinsic *vs* extrinsic risk factors. Intrinsic risk factors are internal characteristics of an athlete that predispose them to injury such as age or sex. Extrinsic risk factors are external influences an athlete is exposed to, such as training load and volume.[18] When reporting on RoB, we reported the result of each domain independently. This informs readers of the current shortcomings and gaps within the literature. A subjective decision was made not to perform a meta-analysis due to the large variation of the included studies regarding injury definition, reporting of injuries and study design.

3. Results

Our search produced 5260 records, of which 865 were removed as duplicates (Fig. 1). During the title and abstract screening, 4267 records were excluded. Screening of 127 full-text articles found 27 eligible for inclusion. The reference lists of all included articles were screened, and two additional eligible studies were identified. The final number of studies that met the inclusion criteria for this systematic review was 29. Prior to consensus the observed inter-rater agreement was 95.1 % (Cohen's kappa = 0.75).

3.1. Characteristics of all included studies

The 29 included studies' publication dates ranged from 1979 to 2021. One study specifically focused on injury and/or injury risk factors in training exposure[19] (Table 1) while four focused on competition exposure.[20–23] The remaining studies did not specify if data was collected during a competition or training period.[6,8,24–44]

Five studies collected data *via* medical encounters.[6,20–23] Seven studies used clinical assessment and self-reported data.[19,27,34–36,40,44] The remaining seventeen studies only used self-reported data.[8,24–26,28–33,37–39,41–43,45] Sixteen studies reported injury and/or injury risk factors for more than one discipline of figure skating,[19,24–26,28,30–34,40–42,44,45] while eleven studies only defined the population as figure skaters and did not specify a discipline.[6,8,20–23,27,35–38] Most of the included studies investigated populations of North America,[26,27,31–33,37,40–44] followed by Europe,[8,19,34] Great Britain,[24,25] and Asia.[36]

Of all the included studies, four collected data prospectively with short follow-up periods (duration of the competition)[20–23] and four studies had longer term follow-up periods ranging from 9 months to 3 years.[34,35,40,44] Most studies (n = 18) used cross-sectional study designs.[8,19,24–27,29–33,36–39,41–43,45] Seventeen of the eighteen studies that used cross-sectional study designs did not specify whether they investigated competition or training exposure.[8,24–27,29–33,36–39,41–43,45]

Ten included studies investigated injury risk factors[8,19,22,24,28,31,37,39,42,44] among 2036 participants. Seven of the ten studies used cross-sectional designs[8,19,24,31,37,39,42] while two studies collected data prospectively.[22,44] One of the studies that collected data prospectively had a short follow-up period (duration of the competition),[22] while the other study had a follow-up period of longer than 1 year.[44]

Our review included 4202 figure skaters from 29 studies; 3113 (74 %) females and 892 (21 %) males. For 197 (5 %) participants, a sex classification was absent or unclear. Of the 4202 participants in our review, 1236 (29 %) participated in synchronized skating, 1043 (25 %) in single skating, 390 (9 %) in ice dancing, and 365 (9 %) in pair skating. The participants' age ranged from 6 to 79 years. Only five studies reported BMI[6,31,37,42,45] and only four studies reported age at which menarche occurred.[8,28,37,42]

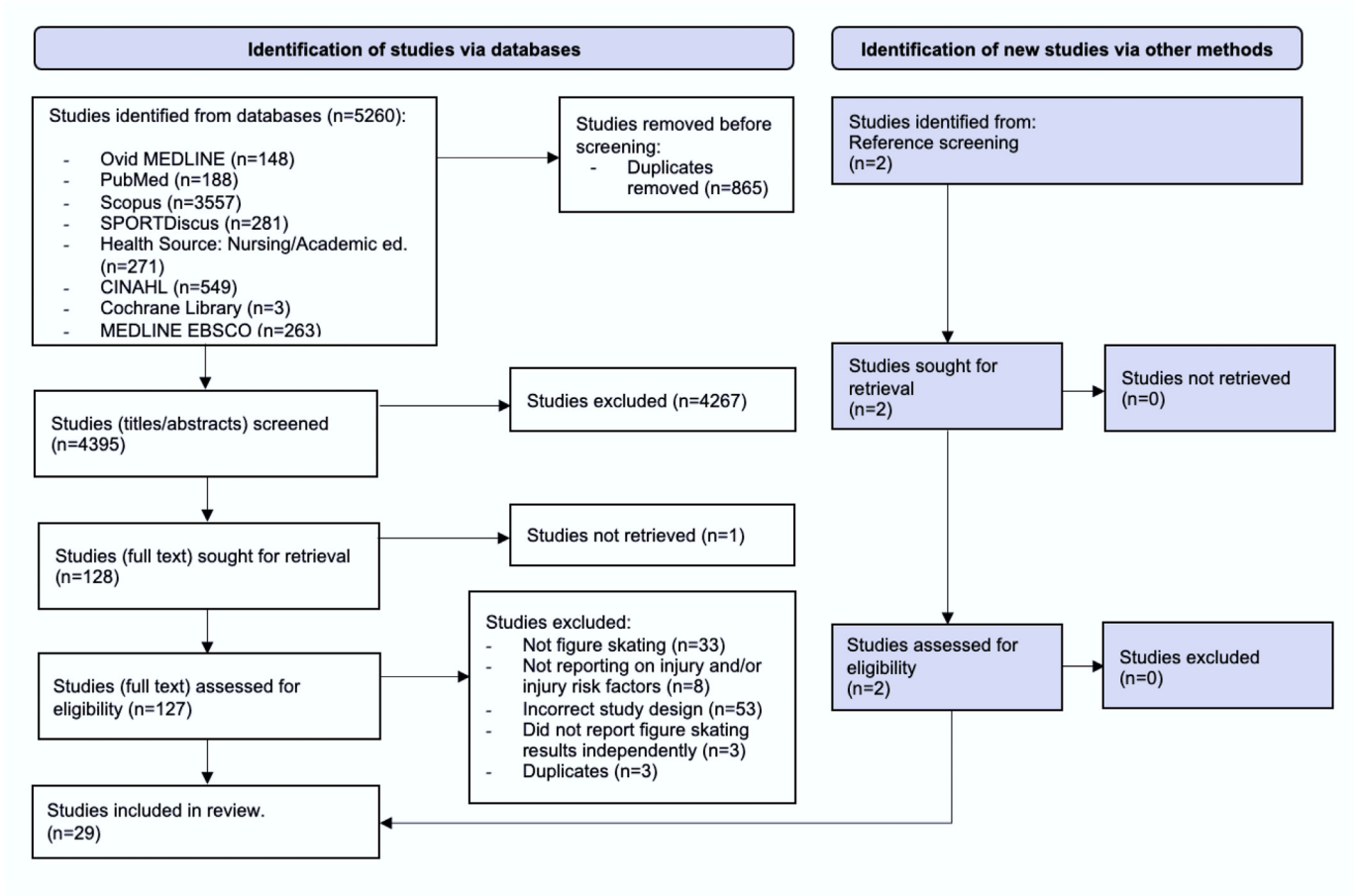


Fig. 1. Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) 2020 PRISMA flow diagram.

3.2. Risk of Bias (RoB) assessment

For the RoB assessment, an observed agreement of 73 % for interrater reliability was recorded before the consensus meetings. There was a significant similarity in the ratings of RoB ($p < 0.001$) between the two reviewers (NS & MS), with Cohen's kappa = 0.612 indicating a moderate level of agreement.

Of the 29 studies included, the statistical analysis domain (domain 6) most frequently (n = 9) scored a lower RoB than the other domains.[6,8,19–21,23,30,37,39] Sixteen of the included studies scored a moderate rating for "study participation" domain.[21,22,24,26–28,31,32,36–42,44] Most studies rated moderate or high RoB for the signaling items "period of recruitment", "place of recruitment" and "inclusion and exclusion criteria". These ratings were due to vague or absent reporting on these parameters. Many of the included studies did not provide any exclusion criteria. Both domains 3 and 4 refer to the method setting of either the prognostic factor measurement or an outcome measurement being the same for all participants. Many of the included studies fell short on this specific signaling item since many of the studies had the same method of collection, but the setting was often not the same for all participants. More than half of the studies did not use a validated outcome measure, resulting in a partial rating for the second signaling item, "Valid and Reliable Measurement of Outcome" in domain 4. Domain 5 ("Study Confounding") was most frequently ranked as having a high RoB. Of the 13 studies[8,19,20,22,24,28,31,35–37,39,42,44] where domain 5 could be rated, eleven[8,20,22,31,35,36,39,40,44] did not account for important confounders resulting in a high RoB for this domain. In domain 6, many studies did not follow a recognized conceptual framework or model[22,24,28,30,32–38,41] (Table 2).

3.3. Epidemiology of injury

Five included studies reported injury prevalence.[8,19,20,24,28] One study reported injury prevalence during training,[19] and only one reported injury prevalence in competition.[20] The prevalence of injury ranged between 2.1 % and 34 %.[19,20] The study that reported the lowest prevalence collected data prospectively and had a short follow-up period (duration of the competition).[20] The study with the highest reported injury prevalence collected data using a questionnaire and clinical assessment, focusing on overuse injuries.[19] Seven of the included studies reported injury incidence.[23,29–32,34,41] One of these studies focused on injury incidence specifically in competition.[23] Only one study reported the injury incidence/1000 exposure hours (1.37 injuries/1000 total training hours).[34] Four studies reported incidence proportions: two reported incidence portions by anatomical region,[29,30] while the other two reported overall injury incidence proportions.[23,31] The final two studies reported injury incidence per participant[32,41] (Online Supplementary Appendix 3).

3.4. Anatomical region and body area

All 29 included studies documented the clinical characteristics of injury.[6,8,19–44] The lower limb[6,8,19,24–34,36–41,43–45] (n = 23, 79 %) and trunk[6,20,24,25,28–37,39–43] (n = 19, 66 %) were the anatomical regions where injuries were reported most frequently by studies, followed by upper limb (n = 13, 45 %)[6,24,25,28–32,34,37,39–41,43] (Online Supplementary Appendix 4). The body area most commonly reported was the knee (n = 19, 66 %)[6,8,19,24–34,36,39–41,43,44] followed by both the foot[6,8,19,24,25,27–34,37,38,40,41,43] and ankle[6,8,19,24,25,27,29–34,36,37,39–41,43]

Table 1
Summary of the characteristics of all included studies.

Author(s) and publication year	Study design	Data collection	Setting (origin of population)	Number of participants (n), number of participants per discipline & level of participation	Age (years) and number of years participating in figure skating.	Sex	BMI
Studies referring to Career Occurrence of injuries (not particularly training or competition based)							
Blewitt and Chockalingam (2011)[25]	Cross-sectional	Self-reported questionnaire	Online (Great Britain)	n = 25 Participants per discipline: Not reported Level of participation: Not reported	18–25 yrs = 7 participants 26–35 yrs = 12 participants 36–45 yrs = 3 participants 46–55 yrs = 1 participant 56–65 yrs = 1 participant 65 + yrs = 1 participant Participants had been skating between 2 and 40 years with an average of 12 years	Females n = 23, Males n = 2	Not reported
Brown and Mckeag (1987)[43]	Cross-sectional	Self-reported questionnaire	Metropolitan Ice rink (United States of America)	n = 14 (all pair skaters) Level of participation: 14 participated in national senior or junior championships 12/14 were nationally ranked 1 year later	Males: Age range 15.2–21.6, mean age 18.1 Females: Age range 12.8–16.0, mean age 14.0 Males participated in pairs skating an average of 3.2 years, females participated in pairs skating an average of 3.4 years	Females n = 7, Males n = 7	Not reported
Davis and Litman (1979)[27]	Cross-sectional	Medical interview & examination of athletes	Minneapolis (United States of America)	n = 45 Level of participation: participating in testing or competitive events	Age range 9–18, mean age 13.5 Number of years participating in figure skating: not reported	Females n = 45	Not reported
Dubravcic-Simunjak et al. (2008)[28]	Retrospective Cohort	Self-reported questionnaire	Online (international skating union members)	n = 412 Junior female: Single n = 78, Pair n = 12, Ice dance n = 20 Senior female: Single n = 97, Pair n = 16, Ice dance n = 22 Junior male: Single n = 47, Pair n = 12, Ice dance n = 20 Senior male: Single n = 50, Pair n = 16 Ice dance n = 22 Level of participation: Elite junior and senior skaters	Age range 12–25 Females: Median age 16, Males: Median age 18 Number of years participating in figure skating: not reported	Females n = 245, Males n = 167	Not reported
Dubravcic-Simunjak et al. (2006)[29]	Cross-sectional	Self-reported questionnaire	Online (teams participating in World synchronized skating Championship in 2004)	n = 528 (all synchronized skaters) Level of participation: skater partaking in an international competition	Female: Age range 15–28, median age 19.4, Male: Age range 18–32, median age 22.2 Number of years participating in figure skating: not reported	Females n = 514, Males n = 14	Not reported
Dubravcic-Simunjak et al. (2003)[30]	Cross-sectional	Self-reported questionnaire	Junior world figure skating championships 1998, 2000, 2001, 2002 (not specified)	n = 469 Female single n = 107 Female pair n = 61 Female ice dance n = 68 Male single n = 104 Male pair n = 61 Male ice dance n = 68 Level of participation: skater partaking in an international competition	Age range 13–20, Females: Median age 16, Males: Median age 18 Number of years participating in figure skating: not reported	Females n = 236, Males n = 233	Not reported

(continued on next page)

Table 1 (*continued*)

Author(s) and publication year	Study design	Data collection	Setting (origin of population)	Number of participants (n), number of participants per discipline & level of participation	Age (years) and number of years participating in figure skating.	Sex	BMI
King et al. (2017)[33]	Cross-sectional	Self-reported questionnaire	Online & at Five United States Figure skating standardized tests 2011 (USA)	n = 204 Single: NQ n = 70, Q n = 66, NI n = 50 Pair: NQ n = 3, Q n = 4 NI n = 15 Ice dance: NQ n = 15, Q n = 12, NI n = 26 *NQ = Not qualified NI = International Q = Qualified	Average age 18.7 ± 6.4, age range NQ 7–37, Q 7–38, NI 12–37 *NQ = Not qualified NI = International Q = Qualified Number of years participating in figure skating: Not reported	Females n = 90 %, Males n = 10 %	Not reported
Naylor and Naylor (2021)[24]	Retrospective cross-sectional	Self-reported questionnaire	Online (United Kingdom)	n = 164 Single n = 118, Pair n = 19, Ice dance n = 25, did not specify discipline n = 2 Level of participation: Below Junior (53.7 %) Junior and above (45.7 %) Did not specify (0.6 %)	Mean age 28.3, median age 28, age range 8–79 Mean years trained regularly 11.7 years (range 10–30) mode 10 years	Females n = 128, Males n = 36	Not reported
Okamura et al. (2014)[36]	Cross-sectional	Medical check-ups by sports doctors & trained official association staff & a self-reported retrospective questionnaire	Japan sports association (Japan)	n = 192 Figure skaters n = 33 Speed skaters n = 159 Level of participation: Competitive athletes at the national athletic meet level.	Figure skaters: Mean age 14.6 ± 1.8, age range 12–18 Skating history: 3.6 ± 1.5 years (0–6 years)	Females n = 100 (speed skaters + figure skaters) Males n = 92 (speed + figure skaters) Female figure skaters n = 87.9 %	Not reported
Pecina et al. (1990)[38]	Cross-sectional	Self-reported questionnaire, interview and an analysis of medical reports	Universidad in Tatra Mountains 1987 & the gold pirouette in Zagreb 1987. (Not specified)	n = 42 Level of participation: World class skaters (skaters competing in international competitions)	Mean age 22.1, age range 17–27 (at time of injury) Number of years participating in figure skating: not reported	With stress fracture: Females n = 5, Males n = 4	Not reported
Simunjak et al. (2020)[39]	Cross-sectional	Self-reported questionnaire with assistance of medical staff or coaching staff	Online & Shanghai trophy 2017, world junior synchronized skating championship & world synchronized skating championship 2018. (Not specified)	n = 708 (all synchronized skaters) Level of participation: Likely representative of the elite synchronized skating population	Junior skaters: mean age 16.23 ± 1.43, median age 16, age range 13–19 Senior skaters: Mean age 20.08 ± 2.63, median age 20, age 15–30 Number of years participating in figure skating: not reported	Females n = 708	Not reported
Smith and Micheli (1982)[41]	Cross-sectional	Self-reported questionnaire & clinical observation examination	Skaters who all trained at 1 rink (United States of America)	n = 19 Level of participation: 19 had completed a third of figure or silver pair test and of these 19, 18 had competed in 1981 US figure skating association regional championship, nine had qualified for sectionals and 3 for nationals	Mean age 13.8, age range 11–19 Participating in figure skating seriously for 4.5 years (range 3–6 years) and average total years skated was 6.2 years (range 4–10 years)	Females n = 15 Males n = 4	Not reported
Studies referring to injuries occurring over a 1-year period (not particularly training or competition based)							
Brock and Striowski (1986)[26]	Retrospective cohort	Self-reported questionnaire	Not specified (Canada)	n = 60 Single n = 29, Pair n = 13, Ice dance n = 18 Level of participation: A & B Team national figure skaters	Average age 18.8 yrs Having participated in figure skating about 11.8 years on average	Female n = 32 Male n = 28	Not reported
Ferrara and Hollingsworth (2007)[31]	Retrospective cross-sectional	Self-reported questionnaire	Online, newsletter & US Adult Nationals 2005 (United States of America)	n = 130 Single n = 90 %, Pair n = 3 %, Ice dance n = 38 %, Synchronized n = 6 % *Some of the participants participated in more than 1 discipline* Level of participation: Competing in local competition n = 38 Competing in regional competitions n = 9	Females: Average age 43 ± 9, age range 34–52, Males: Average age 55 ± 10, age range 35–65 Having participated in figure skating for an average of 12 ± 10 years (range 1–68)	Females n = 113, Males n = 17	Average BMI for both men and women 18.5 kg/m^2 < BMI < 25 kg/m^2

Jederström et al. (2021)[8]	Cross-sectional	Self-reported questionnaire	Online (Sweden)	Competing in national competitions n = 36, Competing in international competitions n = 36 n = 137 Level of participation: Club competition skaters (45 %), star-competition level (39 %), national level skaters (17 %)	Mean age 12.9 Number of years participating in figure skating: Not reported	Females n = 137	Not reported
Kjaer and Larsson (1990)[34]	Prospective cohort	Weekly examination by physician & a questionnaire at year end	Not specified (Denmark)	n = 8 (all single skaters) Level of participation: Participants belonged to team Denmark, the official organization for elite athletes	Mean age 17, age range 14–20 An average training history of 10.0 ± 2.1 years and average competitive history of 7.5 ± 2.3 years	Females n = 5, Males n = 3	Not reported
Smith et al. (1991)[44]	Prospective cohort	Examination	Single Camp held at Olympic training center in Colorado Springs and Pair Camp at the University of Delaware in Newark (United States of America)	n = 46 Level of participation: expected Olympic athletes	Mean age 15.9, age range 10–20 Number of years participating in figure skating: Not reported	Not reported	Not reported
Studies referring to injuries that occurring over a 3-year period (not particularly training or competition based)							
Kujala et al. (1996)[35]	3 yrs longitudinal study	Self-reported questionnaire & magnetic resonance imaging	Questionnaires were completed at participants homes (not specified)	Athletes & non-athletes n = 116 Figure skaters n = 17 Level of participation: Not reported	Athletic females: Age range 10.3–13.3, mean age 11.7 yrs, athletic male: age range 11.3–12.3, mean age 11.9 Nonathletic males: Age range 11.3–12.3, mean age 11.9, Nonathletic female: Age range 11.3–12.8, mean age 11.9 Number of years participating in figure skating: not reported	Athletes: Females n = 31, Males n = 34, Nonathletic: Females n = 17, Males n = 16, Female figure skaters n = 17	Not reported
Studies referring to injuries occurring over a 15-year period (not particularly training or competition based)							
Kowalczyk et al. (2021)[6]	Retrospective chart review	Retrospective charts were reviewed	Medical charts from regional pediatric sports medicine clinics (not specified)	n = 294 Level of participation: Not reported	Females: Mean age 14.1 ± 2.3 Males: Mean age 15.3 ± 2.0 Number of years participating in figure skating: Not reported	Females n = 271 Males n = 23	Mean BMI Females 20.5 ± 2.9 Mean BMI Males n = 21.4 ± 2.6
Studies referring to general participation in figure skating (not particularly training or competition based)							
Burt et al. (2022)[45]	Cross-sectional	Questionnaire, evaluation & scans	Not specified (not specified)	n = 20: Single n = 11, pair n = 3, ice dance n = 6 Level of participation: Figure skaters were training and competing at senior international (n = 11), junior development (n = 9) level	Females: Mean age 19.4 ± 4.9, age range 14.4–28. Males: Mean age 25.2 ± 6.3, age range 16.6–32.6 Female training years: Mean 12.5 ± 6.2 years, range of 4–22 years Male training years: 15.9 ± 7.7, range of 4–26 years	Females n = 11, Males n = 9	Mean BMI Female 20.8 ± 1.7 Mean BMI Male 20.8 ± 1.7
Fortin and Roberts (2003)[32]	Cross-sectional	Individual on-site evaluation and questionnaire	Not specified (United States of America)	n = 208 Single n = 90, Pair n = 60 Ice dance n = 58 Level of participation: data was collected at national skating competition	Age range 10–30 yrs Number of years participating in figure skating: not reported	Single males: Senior n = 18, juniors n = 15, novice n = 12 Single females: Senior n = 20, junior n = 13, novice n = 12 Pair males: Senior n = 18, junior n = 12, Pair females: Senior n = 18, junior n = 12, Ice dance Males: Senior n = 15, junior n = 14, Ice dance Females: Senior n = 15, junior n = 14	Not reported

(continued on next page)

Table 1 (*continued*)

Author(s) and publication year	Study design	Data collection	Setting (origin of population)	Number of participants (n), number of participants per discipline & level of participation	Age (years) and number of years participating in figure skating.	Sex	BMI
Oleson et al. (2002)[37]	Cross-sectional – retrospective	Self-reported questionnaire, interview and bone sonometer	Tertiary care medical center & 3 local skating clubs in Massachusetts (USA)	n = 58 Figure skaters n = 36 Control n = 22 Level of participation: Competitive figure skaters	Control: Mean age 16.8 ± 1.7, Skaters with fracture history: Mean age 15.7 ± 1.5, Skaters with no fracture history: Mean age 16.3 ± 1.9 Number of years participating in figure skating: not reported	Females n = 58	Mean BMI for control 2.1 ± 0.3 Mean BMI for skaters with history of fracture 2.0 ± 0.1 Mean BMI for skaters with no history of fracture = 1.9 ± 0.2
Smith and Ludington (1989)[40]	Prospective study	Examination and self-reported injuries	A single training center & regional, sectionals, nationals & world championships (United States of America)	n = 44 Pair n = 16 teams, Ice dance n = 8 teams Level of participation: Elite pair skaters and ice dancers (17 of the 21 eligible teams attained national rankings)	Average age 20.1, age range 10.9–27.9 Number of years participating in figure skating: Not reported	Senior pair: Females n = 8, Males n = 8, Junior pair: Females n = 6, Males n = 6, Senior ice dance: Males n = 4, Females n = 4, Junior ice dance: Males n = 4, Females n = 4	Not reported
Sugimoto et al. (2021)[42]	Cross-sectional	Self-reported questionnaire	Online (United States of America)	n = 132 Level of participation: Not reported	Females: Mean age 16.8 ± 3.0, age range 10.0–22.0 Number of years participating in figure skating: not reported	Female figure skaters n = 132	BMI: figure skaters with back injury was 21.6 ± 2.7 kg/m. BMI: figure skaters without back injury was 19.3 ± 3.6 kg/m.
Training related studies							
Campanelli et al. (2015)[19]	Cross-sectional	Self-reported questionnaire, clinical examination & measurement of skater's equipment.	Skating Clubs' Facilities (Italy)	n = 76 Single n = 85, Pair n = 10 Level of participation: Not competitive n = 19, participating in local competitions n = 40, participating in national competition n = 19, participating in international competitions n = 17	Age range 6–33, mean age 14.2 ± 5.6 Study only included participants that had been skating at least 1 year	Females n = 75, Males n = 20	Not reported
Competition related studies							
Ruedl et al. (2016)[20]	Cross-sectional	Medical encounters -by medical staff	Winter European Youth Olympic Festival in 2015 (not specified)	n = 899 Figure skaters n = 48 Level of participation: Olympic level athletes	Mean age 17.1 ± 0.8 Number of years participating in figure skating: not reported	Figure skating females n = 30 Figure skating males n = 18	Not reported
Ruedl et al. (2012)[21]	Cross-sectional	Medical encounters -by medical staff	First Winter Youth Olympic Games in Innsbruck-Austria in 2012 (not specified)	n = 1021 Figure skaters n = 66 Level of participation: Olympic level athletes	Mean age 16.6 ± 0.9 (all participants) Number of years participating in figure skating: Not reported	Figure skating females n = 33, males n = 33	Not reported
Soligard et al. (2015)[22]	Prospective	Medical staff-medical encounters	Sochi at 2014 Winter Olympic Games (not specified)	n = 2788 Figure skaters n = 149 Level of participation: Olympic level athletes	Not reported Number of years participating in figure skating: Not reported	Figure skating female n = 74, Figure skating male n = 75	Not reported
Engebretsen et al. (2010)[23]	Prospective	Medical encounters	XXI Winter Olympic Games 2010 (not specified)	n = 2567 Figure skaters n = 146 Level of participation: Olympic level athletes	Not reported Number of years participating in figure skating: not reported	Figure skating females n = 73, Figure skating males n = 73	Not reported

Table 2
Summary of the risk of bias per domain for each included study.

Studies	Study participation	Study attrition	Prognostic factor	Outcome	Study confounding	Statistical analysis
Naylor & Naylor[24]	Moderate	NA	Moderate	Moderate	High	Moderate
Blewitt & Chockalingam[25]	High	NA	NA	Moderate	NA	Moderate
Brock & Striowski[26]	Moderate	NA	NA	Moderate	NA	Moderate
Brown & McKeag[43]	High	NA	NA	Moderate	NA	High
Burt et al.[45]	Moderate	NA	NA	NA	Moderate	Low
Campanelli et al.[19]	Low	NA	Low	Moderate	High	Low
Davis & Litman[27]	Moderate	NA	NA	Moderate	NA	High
Dubravcic-Simunjak et al.[28]	Moderate	NA	Moderate	Moderate	High	Moderate
Dubravcic-Simunjak et al.[29]	Low	NA	NA	Moderate	NA	Moderate
Dubravcic-Simunjak et al.[30]	Low	NA	NA	Moderate	NA	Low
Engebretsen et al.[23]	Low	NA	NA	Moderate	NA	Low
Ferrara and Hollingsworth[31]	Moderate	NA	Moderate	Moderate	High	Moderate
Fortin and Roberts[32]	Moderate	NA	NA	Moderate	NA	Moderate
Jederström et al.[8]	Low	NA	Moderate	Moderate	High	Low
King et al.[33]	High	NA	NA	High	NA	Moderate
Kjaer and Larsson[34]	High	Low	NA	Moderate	NA	High
Kowalczyk et al.[6]	Low	NA	NA	Moderate	NA	Low
Kujala et al.[35]	High	Moderate	Moderate	Moderate	High	Moderate
Okamura et al.[36]	Moderate	NA	Low	Moderate	High	Moderate
Oleson et al.[37]	Moderate	NA	Moderate	Moderate	Moderate	Low
Pecina et al.[38]	Moderate	NA	NA	Moderate	NA	High
Ruedl et al.[20]	Low	NA	Moderate	Moderate	High	Low
Ruedl et al.[21]	Moderate	NA	NA	Low	NA	Low
Simunjak et al.[39]	Moderate	NA	Moderate	Moderate	High	Low
Smith & Ludington[40]	Moderate	Low	NA	Moderate	NA	Moderate
Smith & Micheli[41]	Moderate	NA	NA	High	NA	High
Smith et al.[44]	Moderate	High	Moderate	Moderate	High	Moderate
Soligard et al.[22]	Moderate	NA	Moderate	Moderate	High	Moderate
Sugimoto et al.[42]	Moderate	NA	Moderate	Moderate	Moderate	Moderate

NA: not applicable.

(n = 18, 66 %) and then, the lumbosacral area[6,20,24,28–30,32–37,39–43] (n = 17, 59 %) (Online Supplementary Appendix 4). Bar graph 1 highlights the lower limb body regions with the highest number of reported injuries, categorized in line with IOC consensus statement. The knee, foot, ankle, hip and groin were all frequently injured[25,30,33,39,43] (Bar graph 1).

3.5. Tissue type and pathology type

Bone was the tissue type most frequently reported (n = 21, 72 %),[6,24–30,32–41,43–45] followed by both muscle/tendon[6,19,20,25,26,29,30,32–34,36,40,41,43,44] and ligament and joint capsule[6,19,25–27,29,30,32–34,36,39–41,43] (n = 15, 52 %) (Online Supplementary Appendix 5). The most commonly reported pathology types were fractures (n = 15, 52 %)[6,24–26,29,30,33,35–37,39–41,43,45] and joint sprains (n = 14, 48 %)[6,19,25–27,29,30,33,34,36,39–41,43] followed by bone stress injuries (n = 13, 45 %).[6,24,27–30,33,36–39,41,45] Tendinopathies were reported in 11 (38 %) of studies[19,26,29,30,32–34,36,40,41,44] (Online Supplementary Appendix 5).

3.6. Injury risk factors

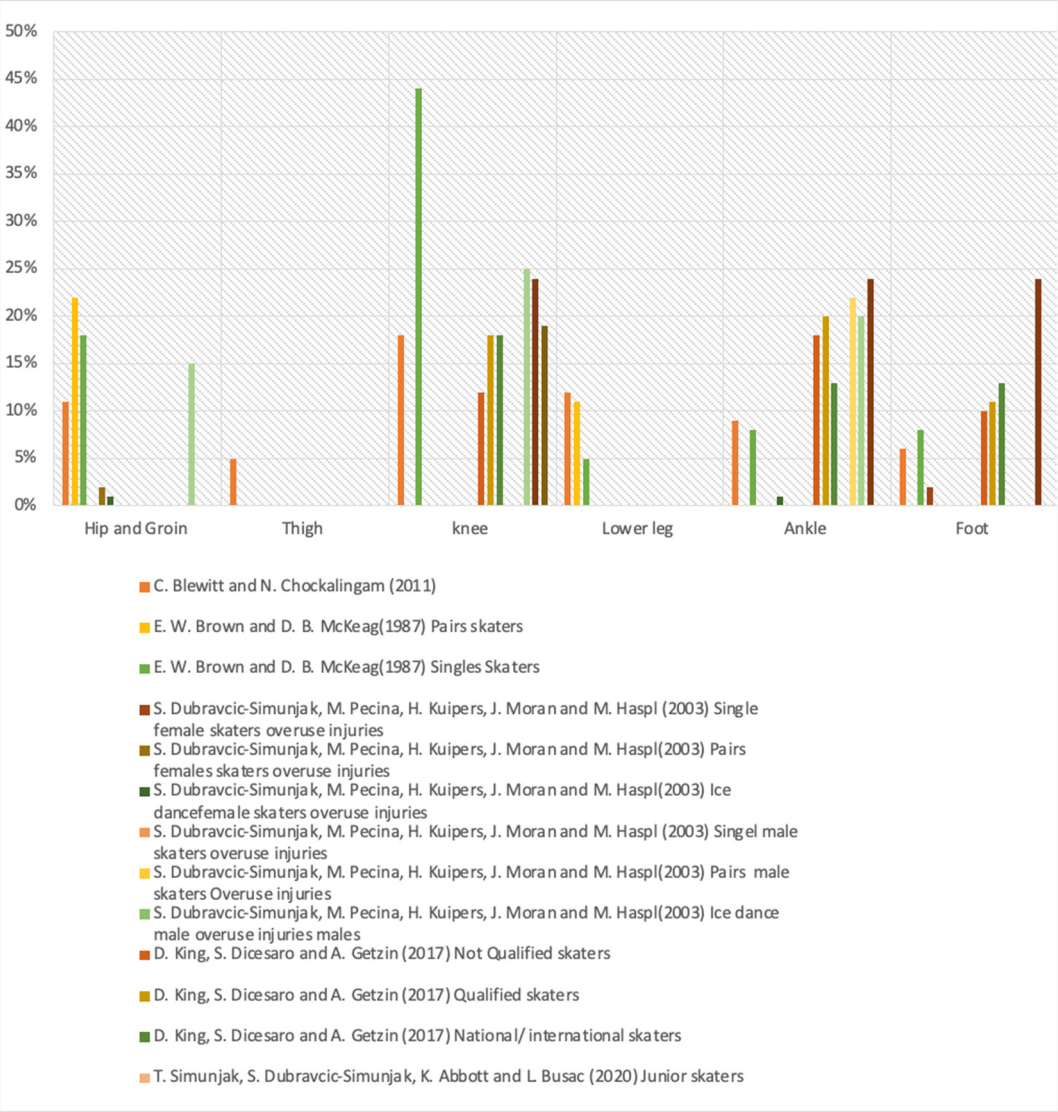
The most frequently investigated injury risk factors included training time and time spent on the ice[8,19,31,42] followed by age,[8,19,39,42] level of participation[8,24,39] and flexibility.[19,44] Significant intrinsic risk factors reported include being older increased the risk for severe injury episodes (OR 1.2, 95 % CI 1.1–1.4, p = 0.002, 7), ongoing injury episodes (OR 1.4, 95 % CI 1.2–0.17 p < 0.001, 7) lower back injuries (OR = 1.211, 95 % CI 1.058–1.3686, p = 0.005, 42), spinal condition (χ^2 = 12.602, df = 1, p = 0.0004)[39] and risk for posterior heel skin callus on the landing foot (OR 1.654, 95 % CI 1.058–3.043, P = 0.025) and the contralateral foot (OR 2.204, 95 % CI 1.122–6.52, p = 0.016) in non-elite skaters.[19] Being younger was associated with an increased risk of sustaining superficial calcaneal bursitis in the contralateral foot in elite skaters (OR 0.576, 95 % CI 0.208–0.939, p = 0.02, 19). A history of a stress fracture was also associated with an increased risk of sustaining a fracture (RR 2.07, 95 % CI 1.28–3.33, p = 0.007, 24). Significant extrinsic risk factors included injury rates being higher in training than in competition (RR: 8.50, 95 % CI 1.96–36.80, p ≤ 0.05, 22), a training frequency of more than 12 sessions per week which increased the risk for sustaining a stress fracture (RR:1.875, 95 % CI 1.08–3.25, p = 0.028, 24), skipped meals per week increased the risk for a severe injury episode (OR: 1.1, 95 % CI 1.0–1.3, p = 0.014, 7) and an ongoing injury episode (OR: 1.1, 95 % CI 1.0–1.3, p = 0.049, 7) (Table 3).

4. Discussion

To our knowledge, this is the first systematic review focusing on the epidemiology and associated risk factors of injury in figure skating. The injury prevalence range in figure skating is 2.1 %–34 %,[19,20] with only one study reporting the injury incidence per 1000 exposure hours (1.37 injuries/1000 total training hours[34]). Currently, the lower limb is reported as the most injured anatomical site (n = 23, 79 %),[6,8,19,24–34,36–41,43–45] mainly affecting the knee (n = 19, 66 %).[6,8,19,24–27,29–34,36,39–41,43,44] The most frequently reported injured tissue type is bone (n = 21, 72 %),[6,24–30,32–41,43–45] with fractures reported as the most frequently reported pathology type (n = 15, 52 %).[6,24–26,29,30,33,35–37,39–41,43] Our systematic review identified 11 risk factors that are significantly associated with injury among figure skaters (three intrinsic and eight extrinsic injury risk factors). When interpreting the findings of this review, it is important to note that this review primarily included female participants, the included studies were exposed to a moderate RoB, and large heterogeneity existed between studies in terms of study design, data collection procedures, injury definitions and populations.

4.1. Injury definition and data collection

Injury definitions and data collection procedures vary greatly in the current figure skating literature. Some studies used medical encounters to capture injuries while others defined injury using time loss. Studies also varied in the definition of injury severity, ranging from 1 day to more than 21 days of lost or altered participation. Although using



Bar graph 1. Demonstrating the percentage of injuries recorded for lower limb body regions per study.

these definitions and data collection methods was previously recommended it can lead to an under-estimation of injury and the burden of injury.

All of the included studies collected a data prior to the IOC consensus statement for recording and reporting injuries in sport was published.[1] We recommend that future researchers define injury in accordance with the 2020 IOC consensus statement of recording and reporting injuries in sport to improve consistency in data collection and reporting across studies.[1]

Ten of the 29 included studies collected data *via* retrospective self-reported questionnaires. Due to recall bias, retrospective self-reported injury data is often unreliable and likely inaccurate.[46] Athletes often cannot recall specific injury details and diagnoses, resulting in underreporting of injuries[46] and possibly contributing further to the underestimation of injuries. Only one included study utilized a long follow-up period (≥1 year).[34,35,44]

4.2. Incidence and prevalence

Only one study reported the injury incidence in terms of injuries per 1000 exposure hours (1.37 per 1000 h of training and 1.72 per 1000 h of ice training).[34] This study only had eight participants who all participated in single skating.[34] Considering the small sample size, we cannot extrapolate these findings to the larger figure skating community at this stage. The incidence proportion of injury per 1000 athletes at the 2010 Winter Olympics Games was lower for figure skating (14 %) compared to other sports (snowboard cross 35 %, bobsleigh 20 %).[23] However, the physical demands of these sports differ from figure skating. Compared to other artistic sports such as ballet (1.24 injuries per 1000 dance hours) figure skating may have a marginally higher injury incidence.[3] Limited studies report injury incidence across the four figure skating disciplines, with conflicting results.[30,32] Among competitive American figure skaters, pair skating had the highest injury incidence, followed by single skating and ice dancing when considering all injuries.[32] In contrast, for overuse injuries, the incidence was the highest for single skating, followed by pair skating and ice dancing among elite junior figure skaters.[30] Given the limited literature and contrasting findings, we cannot make any concrete differentiation between injury incidences for different figure skating disciplines. Overall, there is a lack of consistency in the methods of reporting injury incidence, making it difficult to compare the data.

A wide range of injury prevalence is reported in figure skating (2.1 %–34 %). The higher injury prevalence was specifically documented at training sessions, using a self-reported questionnaire

Table 3
Summary of the significant and non-significant factors associated with injury risk by the number of studies.

	Higher injury risk		Lower injury risk		Unknown direction of association (n)	Total studies (n)
	SIG*	Non-Sig	SIG*	Non-Sig	Non-Sig	
Intrinsic injury risk factor						
Sex – Male	–	1 (24)	–	–	–	1
Previous history of stress fracture	1 (24)	–	–	–	–	1
Increased age	3 (7, 39, 42) ζθϖ	–	–	–	–	3
Decreased age	1 (19) α	1 (19) β	1 (19) χ	–	–	1
Higher body weight	1 (19) δ	–	–	–	–	1
Not reaching menarche	–	1 (28)	–	–	–	1
Extrinsic injury risk factor						
Training frequency	1 (24)	–	–	–	–	1
Level of participation	–	2 (7, 24)	–	–	–	2
Boot-foot length difference	1 (19) ψε	1 (19) ϕ	1 (19) γ	–	–	1
On ice time	1 (19) η	1 (31, 42)	–	1 (19) ε	–	3
Jump height	–	1 (19) δ	1 (19) φ	1 (19) ϕ	–	1
Ankle flexibility	–	1 (19) δ	1 (19) κ	1 (19) λ	–	1
Bendability score	–	–	1 (19) μ	1 (19) π	–	1
Foot arch index	–	–	–	1 (19) ε	–	1
Not reaching menarche	–	–	–	–	1 (28)	1
Stretching & warming up	–	–	–	–	1 (31)	1
Number of hours spent skating	–	1 (42)	–	–	1 (31)	2
Skipped meals	1 (7) θϖ	–	–	–	–	1
Relative energy deficiency in sport indicators	1 (7) ϖ	–	–	–	–	1
Mean weekly training hours of 7–12 h	–	1 (7) θ	–	1 (7) ϖ	–	1
Mean weekly training hours of >13	–	1 (7) ϖθ	–	–	–	1
Quadriceps-inhibited flexion angle of 35°	1 (44)	–	–	–	–	1
Quadriceps-inhibited flexion angle of 14°		–	1 (44)	–	–	1
Hamstring immobility	1 (44)	–	–	–	–	1
Resistance training		–	–	1 (42)	–	1
Training rather than competition	1 (22)	–	–	–	–	1

α: Posterior heel skin callus in contralateral foot and landing foot in non-elite skaters.
β: Retrocalcaneal bursitis in the contralateral foot in elite skaters.
χ: Superficial calcaneal bursitis in the contralateral foot in elite skaters.
δ: Retrocalcaneal bursitis in landing foot of non-elite skaters.
ε: Superficial calcaneal bursitis in landing foot of elite skaters.
ϕ: Lateral ankle skin abrasion in the landing foot of elite skaters.
γ: Toe corn in contralateral foot & landing foot of elite skaters.
η: Lateral ankle skin abrasion in contralateral foot & toe corns in landing foot of elite skaters.
φ: Superficial calcaneal bursitis in the landing foot and lateral ankle skin abrasion in the contralateral foot in elite skaters and posterior heel skin callus in the contralateral foot of non-elite skaters.
κ: Superficial calcaneal bursitis in contralateral foot of elite skaters.
λ: Superficial calcaneal bursitis in landing foot and toe corns in the contralateral foot of elite skaters.
μ: Superficial calcaneal bursitis in landing foot & contralateral foot & lateral ankle skin abrasion in contralateral foot in elite skaters.
π: Retrocalcaneal bursitis in the landing foot of elite and non-elite skaters & lateral ankle skin abrasion in the landing foot of elite skaters.
θ: Ongoing injury episode.
ϖ: Severe injury episode.
ζ: Lower back pain.
ψ: Lateral ankle skin abrasion in the contralateral foot of elite skaters.

followed by clinical examination,[19] while the lower injury prevalence was documented for injuries requiring medical attention at an elite youth event.[20] Recording only medical attention injuries could, once again, result in under-reporting of injuries since not all injured figure skaters will require medical attention during an elite event. Of concern is that prevalence of severe injury episodes (>21 days lost/altered participation) was reported to be as high as 31 %.[8]

4.3. Clinical characteristics

In single skating, lower limb and trunk injuries were the most frequently reported, while in pair skating and ice dancing, lower limb and upper limb injuries were the most frequently reported anatomical regions. Upper limb injuries may be more frequently reported in pair skating and ice dancing since the nature of these two disciplines includes lifts and throw jumps as part of their requirements. Eleven studies reported head injuries, eight of which specifically reported a concussion. Even though head injuries are reported less frequently, it is important to have medical teams experienced in concussion diagnosis and management involved in figure skating to mitigate the risk of potentially delayed impaired cognitive function and mental health problems.[47]

The most frequently injured tissue type reported was bone, while the most commonly reported pathology type was fractures. The acute nature of injuries noted in figure skating could be due to the high risk associated with jumping, spinning, and landing. Falling during these maneuvers results in blunt trauma onto a hard ice surface usually at high velocities.

4.4. Significant injury risk factors

Age was the most commonly reported injury risk factor in figure skating, with older age linked to severe or ongoing injury episodes, an increased risk of lower back injuries, and posterior heel skin calluses on the landing and contralateral feet in non-elite skaters.[8,42] All three studies identifying age as a risk factor used a cross-sectional study design and multivariate analysis,[8,19,42] with two relying solely on retrospective questionnaires[8,42] and the third incorporating a questionnaire, a clinical exam and skater and equipment measurement.[19] Although cross-sectional designs efficiently reveal associations, they limit causality, can introduce bias and confounding, and complicate cohort effect interpretations. Therefore, findings linking age to injury risk in figure skating should be interpreted with caution given these design limitations. Age ranges in the studies varied, with participants

spanning from 8 to 30 years,[39] and one study reporting a mean age of 12.9 years.[8] Notably, figure skating athletes often reach their peak performance at a younger age, with some Olympic competitors as young as 15 and 17 years old. When considering age as a risk factor, it is essential to define what is considered "older" within the context of figure skating. In contrast, younger age is associated with an increased risk of injury in elite skaters.[19]

At the Olympic Games a higher risk for injury was reported during training than in competition.[22] The author followed a prospective study design and collected medical encounters. However, the participants were only followed for the duration of the competition.[22] Another study also reported that training 12 or more sessions per week increased their risk for stress fracture.[24] This same study reported that 44.4 % of the participants trained more than 12 sessions a week.[24] Another study reported the average number of weekly training sessions for pair skaters was 17.4 sessions a week.[43] These training volumes are concerning but could not be compared with other data since most studies reported the training data in hours per week or days per week which cannot accurately be translated into sessions per week. Increased on-ice time significantly increased the risk for lateral ankle skin abrasion in the contralateral foot in elite skaters.[19] The included studies reported a wide variety of skating hours per week which ranged from 4 to 21 h per week. Skipping a meal was also a significant risk factor for a severe and ongoing injury.[8] This risk factor is important as it has been noted that many figure skaters' energy intake is below the recommended values,[48] with a dietary intake that did not meet their energy needs.[49] Decreased mobility was also pointed out as a significant risk factor. Decreased quadriceps mobility was associated with an increased risk for jumper's knee in males, while reduced hamstring mobility increased the risk for patella femoral pain in females. It is important to note that this study used examination, followed skaters for over a year, only made use of univariate analysis and included only single and pair skaters.[44] When interpreting the injury risk factors in this section it is important to consider that many of these risk factors come from a single study and that more research is needed. It is further important to be cognizant of the complex nature of sport injuries. Sport injuries are multifactorial and often occur due to the interaction within a complex system of determinants rather than an isolated factor. Risk factors are often determined in a linear and unidirectional manor.[50] This method does not account for the complex interaction among factors and does not acknowledge the multidirectional interaction between all the factors.[50] Therefore, when considering these risk factors, it is important to acknowledge the unpredictable multidirectional interaction of these factors, including factors which were identified as well as factors which may have been overlooked.

4.5. What this review adds

This is the first review which has attempted to summarize the currently identified intrinsic and extrinsic risk factors in figure skating. Previous reviews have been published on figure skating injuries.[5,7,9–11] One of these reviews focused on event preparation and side line converge at figure skating events.[11] Another one of these reviews only focused on injuries in synchronized skating and at the time of the review only one study had been published specifically in synchronized skating.[9] Two of these reviews also concluded that lower extremity injuries were more common than the upper extremity injuries.[5,7] One of these reviews further highlighted that ankle sprain were the most common acute injury[7] while the other review suggested that ankle sprains could most likely be the most common injury. Our review identified fractures to be the most commonly reported pathology type followed by sprains. One of the reviews briefly mentioned the lack of a standardized injury definition[7] and two of the reviews mentioned that data were collected retrospectively and that this could lead to recall bias[5,7] but provided no further detail on the methodological rigor of the included studies. Although many of these reviews, as well as our own, consistently report the lower limbs as the most frequently injured anatomical region, it is important to acknowledge the variation in injury definitions across studies. Aligning future injury reporting with the IOC framework will facilitate the pooling of data, ultimately leading to more consistent and definitive conclusions regarding the most commonly injured body areas and tissue types.

4.6. Limitations

We searched eight electronic databases and screened the references of all included studies. However, one study we deemed relevant based on title and abstract could not be retrieved. This study was unavailable in the listed journal and our multiple attempts to contact the corresponding author failed. In this review, we limited the studies to those published in English. Even though most sport injury literature is published in English, we may have excluded a relevant article published in a different language. Since 1990, figure skating has become more demanding with compulsory figures being removed and assigning a higher priority to a variety of jumps. This change in the technical demand for figure skating could have exposed figure skaters to different injuries and contributors to injury risk. Five of the included studies[24,28,37,38,45] only focused on reporting injuries related to stress fractures and/or acute fractures. This may have contributed to bone being reported as the most commonly injured tissue type and fractures as the most commonly injured pathology type.

Due to the heterogeneous nature of the data in included studies a narrative synthesis systematic review was conducted. Certain findings, such as the reported prevalence of lower limb injuries and the focus on age as a risk factor, may reflect observational trends and require cautious interpretation, especially given the variability in data quality and study designs across current research. Multiple tools exist to assess risk of bias, however currently there are no tools which are specially designed to assess risk of bias in observational studies. The QUIPS tool has been widely used but needs to be optimized for studies that do not report prognostic factors or follow a prospective study design. There is a need for a tool which is more specifically designed to assess risk of bias in observational studies.

4.7. Clinical implication

This review identified several significant intrinsic and extrinsic injury risk factors in figure skating. Although many of these risk factors were reported in individual studies, they are noteworthy because they are modifiable, such as training frequency exceeding 12 sessions per week, increased on-ice time, skipping meals, and decreased mobility. Clinicians working with figure skaters should be particularly attentive to these modifiable risk factors. Applying this knowledge in the context of the specific athlete can guide the design and implementation of effective risk management strategies, ultimately helping to prevent injuries and optimize performance for figure skating.

4.8. Recommendation for future research

The quality of evidence on figure skating injuries and injury risk factors is poor. To help inform injury prevention strategies, we advise that research pertaining to figure skating should follow a prospective study design with a long follow-up period. Further, future researchers should consider using consistent injury definitions in line with the IOC consensus statement[1] and use a recognized framework when reporting injury data. This will allow for the comparison of data collected across various studies. It is also recommended that future research should validate questionnaires prior to data collection. When investigating risk factors, researchers should ensure that all confounders are considered to avoid a reductionist approach to risk factor assessment with inaccurate, misleading conclusions. Further, more information is needed on the epidemiology of injury and injury risk factors per discipline rather than across

figure skating, since the nature of these disciplines and associated mechanical loads vary. The limited research currently available at present shows different injury patterns and potentially different injury incidences and prevalences. However, more data will be needed to provide insight for medical professionals caring for these athletes. Most of the population in the available literature consisted of female figure skaters; more research is needed on male figure skaters as the injury patterns may differ from female figure skaters especially in disciplines such as pair skating and ice dancing where their role is entirely different from female skaters. Only six studies published since 2019 report figure skating injuries and/or injury risk factors.[6,8,24,39,42,45] This once again highlights the critical need for more research in this sport.

5. Conclusion

Good quality research investigating figure skating injuries and injury risk factors is scarce. Overall, studies investigating the epidemiology of injury and injury risk factors are exposed to a moderate risk of bias. The injury prevalence ranged from 2.1 % to 34 %. These values may be an underestimation of the burden of injury due to the data collection methods and injury definitions used across the included studies. While fractures, joint sprains, and bone stress injuries are most commonly reported, variation across the literature in terms of injury definition and data collection has prevented us from definitively stating whether these are the most common injuries in figure skating. This lack of clarity highlights the critical need for more standardized research approaches to accurately determine injury incidence and prevalence in this sport. Being older was the most frequent and well-researched risk factor for identified injuries. Our review identified three significant intrinsic and eight significant extrinsic risk factors. Many of the risk factors identified were only reported by individual studies. Although these risk factors require further research within figure skating, when combined with that from other sports, suggests that coaches and clinicians should be mindful of these modifiable risk factors. In general, more consistent data generation following a recognized framework and injury definitions is needed. Advances in figure skating injury and injury risk factor research will aid in developing and implementing evidence-based injury prevention strategies, ultimately allowing safer participation in the sport.

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Confirmation of ethical compliance

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CRediT authorship contribution statement

Natasha T. Schmidt: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Dina C. Janse van Rensburg:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Marlene Schoeman:** Formal analysis, Data curation, Writing – review & editing. **Manuela Besomi:** Data curation, Writing – review & editing. **Audrey Jansen van Rensburg:** Data curation, Writing – review & editing, Resources. **Dan Garnett:** Data curation, Writing – review & editing. **Susan Scheepers:** Data curation. **Carel Viljoen:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – review & editing, Supervision.

Declaration of competing interest

All authors declare that there is no conflict of interest (*i.e.*, personal associations or involvement as a director, officer, or expert witness).

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