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University of Pretoria

Faculty of Health Sciences

Department of Physiotherapy

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

A dissertation in fulfilment of the requirements for the degree Masters of Physiotherapy

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**Supervisor:** Dr. Carel Thomas Viljoen (University of Pretoria)

**Co-supervisor:** Prof. Dina Christa Janse van Rensburg (University of Pretoria)

## DECLARATION

I, the undersigned, declare that the dissertation hereby submitted to the University of Pretoria for the degree Master in Physiotherapy and the work contained therein is my own original work and has not previously, in its entirety or in part, been submitted to any university for a degree.

Signed  this 01 day of September 2023

## DEDICATION

*To my dad, Rudi*

## ACKNOWLEDGEMENT

I would firstly like to thank my supervisor Dr. Carel T Viljoen. Thank you for your guidance and exceptional mentorship. I have grown so much throughout this process and have learnt more than I thought possible, your expectations made me work harder, and your high standards gave me something to strive for.

Secondly, I would like to thank my co-supervisor and co-authors. A systematic review is a mammoth task that can only be completed by team of dedicated individuals. I am very fortunate to have had a team of individuals with so much knowledge and passion. Thank you to all of you for taking such keen interest in sport I am so passionate about.

Lastly, I would like to thank my parents, you have taught me what hard work and dedication is and I am so grateful for the wonderful example you have set. I am who I am because of you, and I owe every success to you.

## SYNOPSIS

**Title:** Epidemiology and associated injury risk factors in figure skating: a systematic review

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**Degree:** M. PhysT

**Background:** Figure skating is a mode of physical activity that is technically and aesthetically demanding, requiring athletes to perform jumps, spins, throws and lifts. The technical demand of figure skating has increased in recent years**.** The escalated technical demand is predicted to increase the number of figure skaters presenting with injuries.

**Objective:** To identify and critically appraise the available evidence on the epidemiology of injury and injury risk factors in figure skating.

**Design:** Systematic review.

**Data Source and search strategy:** Eight databases were searched for relevant studies from inception 02 June 2022 to 28 April 2023 together with manual reference searching. The search strategy was developed by the lead author under the supervision of a Medical Librarian and the main supervisor. Two sets of keywords were developed to address our research aims. The results of the first set of keywords were combined with an OR operator followed by the second set. Thereafter, an AND operator combined the two sets of keywords.

**Study Selection Criteria and study selection:** Studies reporting on the epidemiology of injury and/or investigating injury risk factors in figure skating were included. The identified studies were imported to EndNote 20 to identify and remove duplicates. Two researchers independently screened the titles and abstracts for potentially eligible studies. The two reviewers then independently screened the full texts of the studies identified as eligible based on title and abstract screening. Any discrepancies in selection between the two reviewers was resolved via consensus. To ensure all potentially relevant studies were included, one reviewer screened the reference lists of all included studies.

**Data Extraction:** The included studies were distributed to four of the six authors for data extraction on a standardized data extraction sheet. One researcher extracted data from all included studies for quality control.

**Data Analysis:** Meta-analysis could not be completed due to the heterogenous nature of the studies.

**Risk of Bias:** Risk of bias (RoB) was assessed using the quality in prognostic factor studies tool. A meeting was held between two authors where each domain and signalling item of the tool was discussed to ensure inter-rater reliability and they optimised the tool for use. The RoB was assessed independently per domain and ranked as either high or a low RoB. Two authors independently assessed the RoB of

each included study. Discrepancies were resolved through consensus meeting between the two authors. 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, with Cohen's kappa=0.612 indicating a moderate level of agreement.

**Results:** Twenty-nine studies were included. The prevalence range was 2.1%-34%, and the incidence, of injury was 1.72 per 1000 hours of ice training. The most frequently injured anatomical region was the lower limb, particularly the knee, foot and ankle with the most reported pathology types were fractures and sprains. Significant intrinsic injury risk factors included an older age, previous history of stress fracture and a higher body mass. Significant extrinsic injury risk factors included training more than 12 sessions per week, skipping meals, relative energy deficiency in sports indicators, hamstring and quadriceps immobility, training rather than competing, increased time on-ice time and boot-foot length difference. The quality of evidence on figure skating injuries and injury risk factors is poor. More than half of the studies did not use a validated outcome measure and many of the studies did not consider important confounders. None of the included studies defined injury according to the 2020 IOC consensus statement of recording and reporting injuries and many studies did not follow a recognized conceptual framework or model.

**Conclusion** The incidence of figure skating injuries per 1000 hours was higher than in other artistic sports such as ballet. The most frequently injured anatomical region was the lower limb and the most common pathology types were fractures and sprains. Overall, our review identified three significant intrinsic and eight significant extrinsic risk factors. More consistent data reporting and injury definitions is needed.

**PROSPERO registration number:** CRD42021293641

**Key words**: Figure skating, injury, risk factors, epidemiology

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| BMI | Body Mass Index |
| CI | Confidence Interval |
| IOC | International Olympic Committee |
| ISU | International Skating Union |
| OR | Odds Ratio |
| PERSiST | implementing Prisma in Exercise, Rehabilitation, Sport medicine and Sports science |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| PROSPERO | International prospective register of systematic reviews |
| QUIPS | Quality in prognostic factor studies |
| RoB | Risk of Bias |
| RR | Risk Ratio |
| SAFSA | South African Figure Skating association |
| UK | United Kingdom |
| U.S | United States |

**Abbreviations for Researches**

| | |
|---|---|
| AJvR | Audrey Jansen van Rensburg |
| CJvR | Christa Janse van Rensburg |
| CV | Carel Viljoen |
| DG | Dan Garnett |
| MB | Manuela Besomi |
| MS | Marlene Schoeman |
| NS | Natasha Schmidt |
| SS | Susan Scheepers |

# CHAPTER 1

## Introduction

# 1. Introduction

This chapter aims to provide a background on figure skating and figure skating injuries. The chapter then moves into the problem statement, research question, aims and objectives. It also covers the research design, assumptions and delineations and significance of the study. It further contains a table with the definition of key terms as well as a figure explaining the research strategy. This chapter will conclude with a descriptive outline of each chapter forming part of this thesis.

## 1.1 Background

Figure skating is a mode of physical activity that is technically very demanding, requiring athletes to perform jumps, spins, throws and lifts (Miller and Thompson, 2020). The sport also is not only technically demanding but also aesthetically demanding (Kowalczyk et al., 2021). The sport is governed by the International Skating Union (ISU) (ISU, 2023b). Currently, the ISU has more than 90 countries registered as members explicitly for figure skating worldwide (ISU, 2023b). Figure skating is the oldest sport in the Olympic Winter Games programme, having been a part of two Olympic Summer Games before the first Olympic Winter Games (IOC, 2021). The most sought-after competitions include the Winter Olympics and the Winter Youth Olympic games. In 2024, the Winter Youth the Olympic Games will be hosted in Gangwon (Republic of Korea), with the qualifying period from 1 January 2022 to 8 December 2023 (ISU, 2023b). The next Olympic games will then follow in 2026 and will be hosted in Milano Cortina (Italy).

The South African Ice-Skating Association was established in 1937 and is today known as the South African Figure Skating Association (SAFSA) (SAFSA, 2023). The South African Figure skating association has been a member for the ISU since 1938 (SAFSA, 2023). Only five South African skaters have qualified for the Winter Olympic Games since 1960 (SAFSA, 2023). In the 2022 season, the Gauteng North Figure Skating Association (GNFSA) had 115 skaters registered with SAFSA. Gauteng North is only one of five regions belonging to SAFSA (GNFSA, 2022).

Figure skating is divided into four disciplines: single skating, pair skating, ice dancing and synchronized skating (ISU, 2023b). Single skating is performed by either a man or woman alone, often characterized by the performance of a short program and a free skate (U.S.FigureSkating, 2023). Each program is filled with jump and spin elements as well as a step sequence (U.S.FigureSkating, 2023). Pair skating, like single skating, has a short and free program. In this discipline, a man and women skate side by side, doing solo jumps and spins in unison as well as performing lifts and throw jumps (U.S.FigureSkating, 2023). In addition, these pairs will also perform shadow skating and mirror skating (U.S.FigureSkating, 2023). Ice dancing also consists of a man and a woman who perform together, but these skaters perform a rhythm dance and a free dance. Ice dancers will not perform jumps and spins but rather focus on lifts, dance patterns and step sequences within a specific tempo and range (U.S.FigureSkating, 2023).

Synchronized skating consists of a team of skaters (8-20) who will perform a short and a free program (U.S.FigureSkating, 2023). In these programs, the skater will perform intricate formations and step sequences. Synchronised skating is the only discipline not currently an Olympic sport (U.S.FigureSkating, 2023).

To understand the ISU Judging system, you must first understand that participants competing in competitions will participate in two events per competition, including a short program and a free skate (U.S.FigureSkating, 2023). The winner of the competition will be the skater who obtains the highest final score. The final score is composed of the sum of segment scores from both the short and free programs. The segment score comprises a technical score and a presentation score. The technical score refers to how well the elements are performed. Elements refer to the jumps, spins, lifts, throws and step sequences performed in each program (U.S.FigureSkating, 2023). Each element receives a base value, and the judge will then give the specific element a grade of execution. The grade of execution allows judge to add value to each element if an element was executed well or deduct value from the base value of an element if it was executed poorly (U.S.FigureSkating, 2023). The range for grade of execution is between +5 and -5. For the performance score, the judges score the presentation of the program. The performance score is divided into three components. The first component is composition. Composition refers to how well the program is choreographed in the context of the music; the flow of the program and how well the program covers the surface area of ice (U.S.FigureSkating, 2023). The second component is presentation. Presentation refers to how well the skaters keep in time with the music, the variability of energy within a program, and special awareness. The third and final component of the performance score is skating skills. Skating skills refer to the diversity of edges and how well they are performed. Skating skills also refer to the speed, power and balance in a program (U.S.FigureSkating, 2023). These three components are scored on a scale from 0.25 to 10 with increments of 0.25. The final score of a program refers to the sum of technical score and performance score minus any deductions. The deductions can be incurred for any falls or rule violations. The total of both program segment scores are then added together to form a final score. The skater with the highest overall final score wins the competition (U.S.FigureSkating, 2023).

The technical demand of figure skating has increased in recent years (Kowalczyk, Geminiani, Dahlberg, Micheli and Sugimoto, 2021; Dubravcic-Simunjak, Pecina, Kuipers, Moran and Haspl, 2003). A significant change in the technical demand of the sport occurred in 1990 (Dubravcic-Simunjak et al., 2003) when compulsory figures were removed, allowing more focus on a wider variety of jumps. Along with the development in technical demand, figure skating has grown in popularity worldwide (Porter, Young, Niedfeldt and Gottschlich, 2007). In the United States alone, the U.S. Figure Skating Association recorded 222 890 skaters for the 2021-2022 seasons (U.S.FigureSkating, 2022). On average, figure skaters start organised training from five years old. Typically, figure skaters have a

demanding training schedule of up to 15 hours on ice and an additional 15 hours of off-ice training per week (Mohney, Miller and Hanson, 2017). 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 (Han, Geminiani and Micheli, 2018).

Currently there is a large body of quantitative literature on the epidemiology of injury in figure skating. The prevalence of figure skating injuries is as high as 34% (Campanelli, Piscitelli, Verardi, Maillard and Sbarbati, 2015), while the incidence is 1.72 injuries per 1000 hours of ice training (Kjaer and Larsson, 1992). The literature also reports a number of intrinsic and extrinsic risk factors for figure skating injuries. Currently, there are five reviews on figure skating injuries (Abbott et al., 2013; Bradley, 2006; Han et al., 2018; Lambrinakos-Raymond et al., 2019; Porter et al., 2007). All of the reviews identified were narrative reviews.

In 1992 van Mechelen *et al* described a framework for injury prevention namely, "the sequence of prevention" (van Mechelen, Hlobil and Kemper, 1992). The framework has four steps; Step 1 establishes the extent of injury, Step 2 establishes aetiological mechanisms of injury, Step 3 introduces a preventative measure based on the risk factors identified in Step 2, and Step 4 assesses the efficacy and/or effectiveness of the preventative measure by repeating Step 1 (van Mechelen et al., 1992). To design injury risk management strategies, we will need to follow the framework described by Mechelen *et al* and for the purpose of this thesis we have used step one and two of the "sequence of prevention" to design a framework for the current thesis (Figure 1). Furthermore, it is important to review the risk factors identified in content of the risk of bias of the literature from which the risk factors are identified. Having a summary of available literature guides future research on the gaps in literature and how to improve the risk of bias of future research.

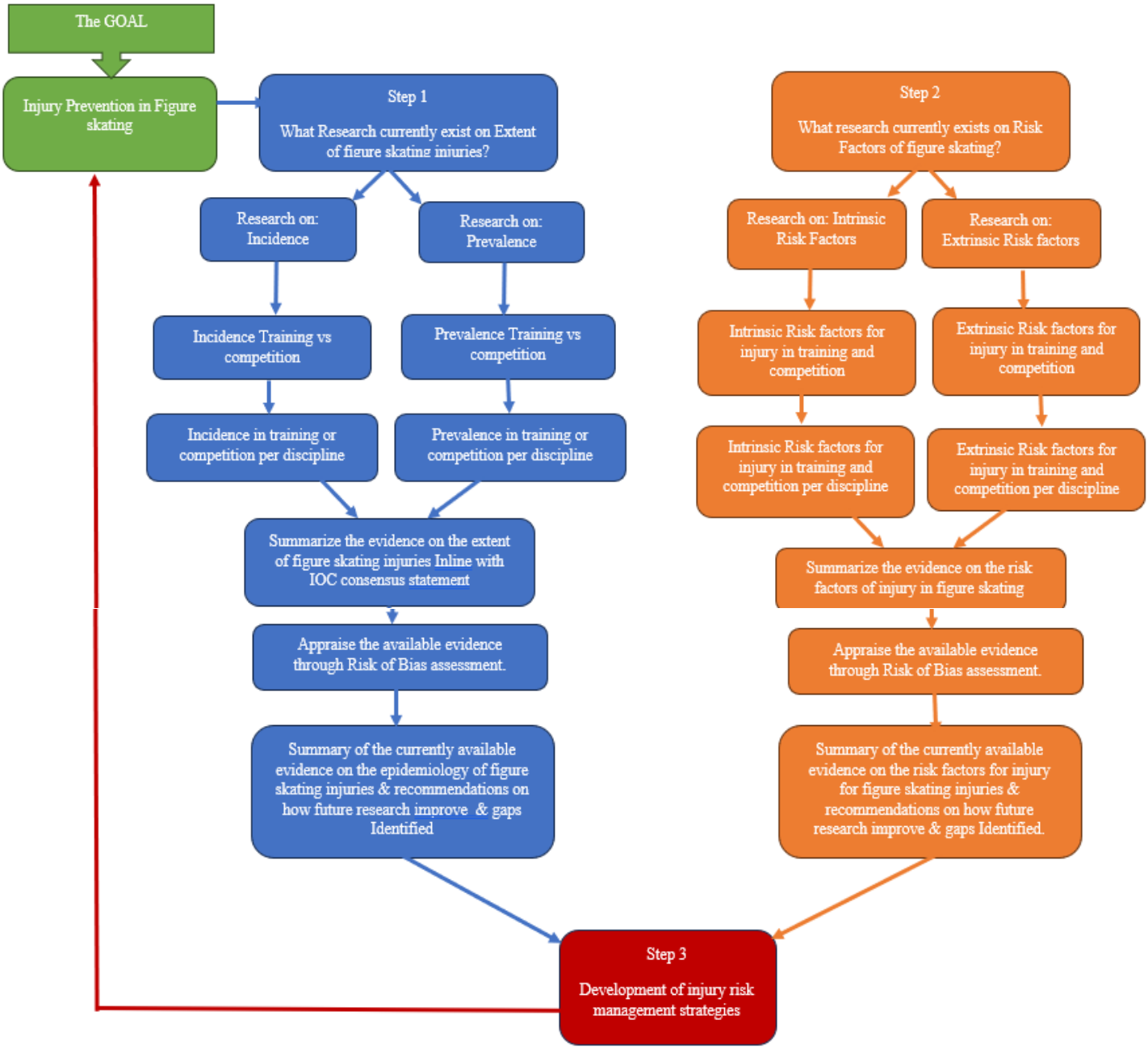


**FIGURE 1: Theoretical frame based on "the sequence of prevention".**

## 1.2 Research Problem

Previous reviews were published on figure skating injuries (Han et al., 2018; Porter et al., 2007; Abbott and Hecht, 2013; Bradley, 2006; Lambrinakos-Raymond, FitzGerald and Geminiani, 2019). To my knowledge there are no systematic reviews that have been conducted to systematically identify, review, summarise, and critical appraise the available evidence on figure skating injuries and injury risk factors.

## 1.3 Research Question

What is the epidemiology of injury and the associated injury risk factors in figure skating?

## 1.4 Aims

To identify, critically appraise, and summarize the current evidence on the epidemiology of injury and the associated injury risk factors in figure skating.

## 1.5 Objectives

1.5.1 Identify the epidemiology (incidence, prevalence, and frequency) of injury and associated injury risk factors of figure skating using a predetermined search strategy.

1.5.2 To critically appraise the included studies level of evidence using the Oxford Centre of Evidence Based Medicine (OCEBM) model.

1.5.3 Critically appraise the risk of bias of included studies using the Quality in Prognosis Studies tool (QUIPS).

1.5.4 Summarize current existing evidence in two main categories of training vs competition injuries and sudden vs gradual onset injuries. Where possible, the summary of the data will be subdivided into the various disciplines within figure skating.

## 1.6 Research Design

A prevalence and risk systematic review was conducted. A prevalence review measures the disease burden of a particular population. A risk review focuses on an existing relationship between an exposure and a specific health outcome and to what extent (Munn, Stern, Aromataris, Lockwood and Jordan, 2018). This systematic review was completed per the 2020 Preferred Reporting Items for Systematic Review and Meta-analysis (PRIMSA) guidelines (Page, McKenzie, Bossuyt, Boutron, Hoffmann, Mulrow et al., 2021).

## 1.7 Significance / Contribution

Currently, there are no systematic reviews on the epidemiology of figure skating injuries and injury risk factors. Conducting a systematic review on the epidemiology of injury and the associated injury risk factors in figure skating will summarise the extrinsic and intrinsic risk factors for injury. The extrinsic risk factors can then be used together with frequently injured body areas and pathology types to create injury risk management strategies. This systematic review further comments on the risk of bias of the

existing evidence which can guide future researchers on how to improve future literature and address the gaps identified.

## 1.8 Assumptions

We must assume that our search strategy was thorough enough to retrieve and have access to all studies. An additional assumption in this research was that all results reported in the included studies were reported honestly and accurately.

## 1.9 Delineation

The scope of this review was limited to the epidemiology of figure skating injury and associated injury risk factors. My research did not focus on injury prevention strategies and cannot be used to make assumptions or decisions on injury prevention. A meta-analysis could not be performed due to the heterogeneous nature of the data of the included studies. This systematic review was further limited to quantitative studies.

## 1.10 Definition of Key Terms / Concepts

The table below (Table 1) aims to highlight the conceptual definition as well as operational definitions of various key terms or concepts which will be used throughout the thesis.

**TABLE 1: Definition and conceptualisation of key terms/concepts**

| Key Term/ Concept | Conceptual definition | Operational definition |
|---|---|---|
| Epidemiology | "a branch of medical science that deals with the incidence, distribution, and control of disease in a population" (Marriam-Webster, 2023) | Epidemiology will include prevalence, incidence, frequency, and injury severity in this systematic review. |
| Injury | "is tissue damage or other derangement of normal physical function due to participation in sports, resulting from rapid or repetitive transfer of kinetic energy." (Bahr, Clarsen, Derman, Dvorak, Emery, Finch et al., 2020) | Injury definition in studies may vary, but as part of our data extraction, we will record how each included study defined injury. |
| Risk Factors | "a condition, behaviour, or other factor that increases risk." (Dictionary.com, 2023) | The definition of a risk factor will be the same for the purpose of this study. Risk measures may have been reported differently amongst studies. We will report the risk measure in line with that of the included studies (i.e. Odds Ratio (OR) & Risk Ratio (RR)) |

| Key Term/ Concept | Conceptual definition | Operational definition |
|---|---|---|
| Figure Skating | "Figure skating is a unique and highly technical sport involving jumps, spins, footwork, dancing, and even acrobatics all on ice skates."(Miller et al., 2020) skating consists of 4 disciplines namely; single skating, pair skating, ice dancing and synchronized skating. | The definition of figure skating will be the same for the purpose of this study. Any study that defines their population as figure skaters or defines their populations partaking in one of the four disciplines will be considered for inclusion |
| Systematic Review | "Systematic reviews seek to collate evidence that fits pre-specified eligibility criteria in order to answer a specific research question. They aim to minimize bias by using explicit, systematic methods documented in advance with a protocol." (Higgins JPT, Thomas J, ChandlerJ, M, Li T, Page MJ et al., 2022) | Our systematic review will collate evidence on epidemiology (incidence, prevalence, severity, and frequency) and associated risk factors of injury in figure skating. |
| International Skating Union | International skating union is an international sport federation that governs all ice skating sports across the world (ISU, 2023b). | In this review the ISU may be used to determine whether a competition referred to in a study was a figure skating competition. |
| Single skating | Singles skating is often characterized by the performance of programs by an individual (either male or female) skaters containing jumps, spin elements and step sequence (U.S.FigureSkating, 2023).<br>Singles skating is often characterized by the performance of programs by an individual (either male or female) skaters containing jumps, spin elements and step sequence (U.S.FigureSkating, 2023). | In this review the definition of single skating will be the same. Any study that defines their population as single skaters will be reviewed for inclusion.<br>In this review the definition of single skating will be the same. Any study that defines their population as single skaters will be reviewed for inclusion. |
| Pair skating | Pairs skating is characterized by a male and a female who perform programs together, including side-by-side jumps and spins as well as throw jumps, lifts and mirror skating (U.S.FigureSkating, 2023). | In this review the definition of pair skating will be the same. Any study that defines their population as pair skaters will be reviewed for inclusion. |

| Key Term/ Concept | Conceptual definition | Operational definition |
|---|---|---|
| Ice dancing | Ice dancing is characterised by a male and a female who skate side by side performing lifts a, dance patterns and step sequences within a specific tempo and range (U.S.FigureSkating, 2023). | In this review the definition of ice dancing will be the same. Any study that defines their population as ice dancers will be reviewed for inclusion. |
| Figures | "Figures, refer to circular patterns which skaters trace on the ice to demonstrate skill in placing clean turns evenly on round circles. These circles are skated using one foot at a time, as a skater masters balance, control, flow and edge to achieve clean and accurate tracings" (U.S.FigureSkating, 2023). | In this study the definition of figures will be the same. |

**Research Procedure and Strategy**

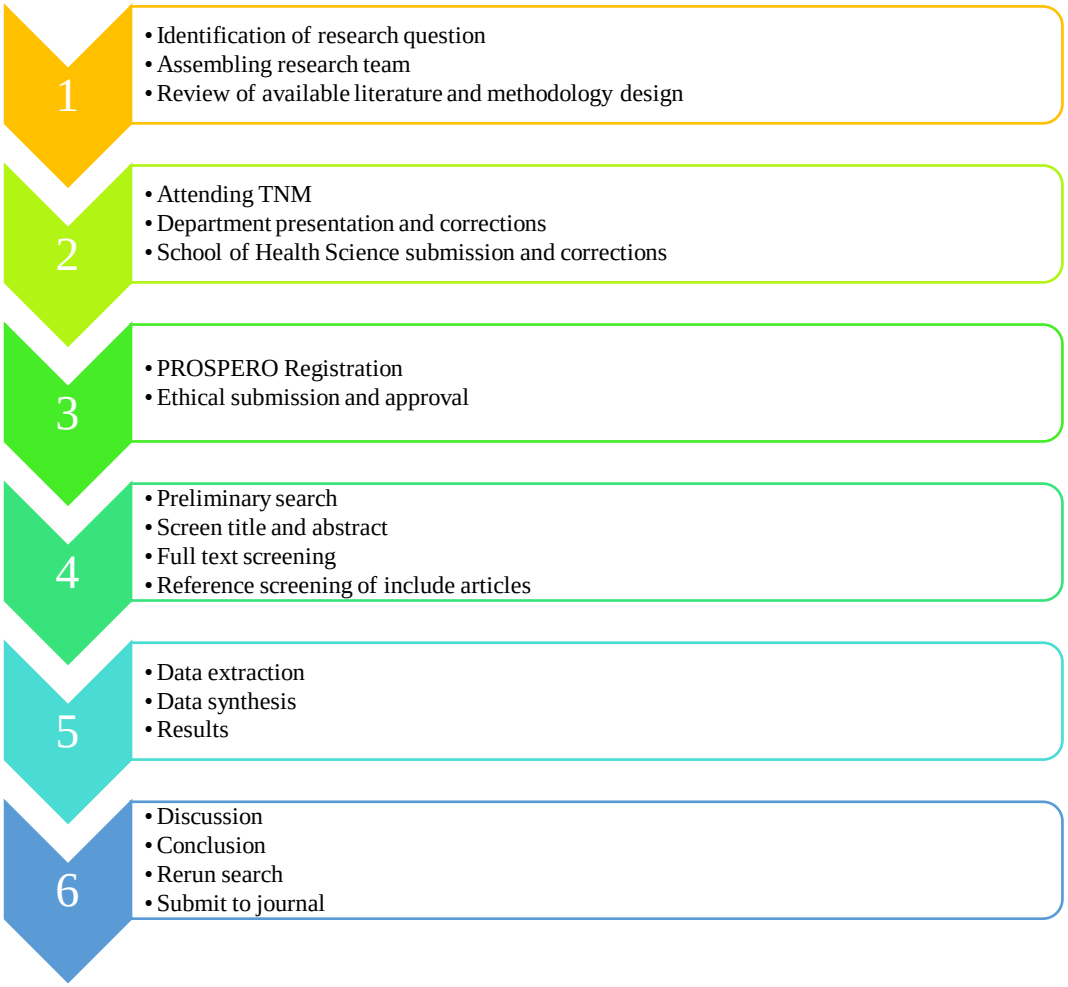


**FIGURE 2: Outline of the research procedure and strategy**

## 1.11 Flow of the thesis.

**Chapter Two** is the submitted manuscript entitled "Gaps in the knowledge of injuries related to figure skating and future research directions: A narrative review"**.** The manuscript provides an overview of the current literature on the epidemiology of figure skating injuries and associated injury risk factors. The manuscript highlights the need for a more focused summary of the available evidence.

**Chapter Three** is the submitted manuscript entitled "Epidemiology and associated injury risk factors in figure skating: a systematic review". The manuscript was submitted to the Journal of Athletic Training and is presented in the formatting guidelines as required by the Journal of Athletic Training. At the time of submitting this thesis for the purpose of examination, the manuscript's status was "under review".

**Chapter Four** will consist of a discussion of the findings of chapter three, clinical recommendations, research recommendations and final concluding statements based on the findings of chapter three**.**

**Annexures**, including the online supplementary appendices forming part of Chapter 3's submitted manuscript, are presented at the end of the thesis.

**Table 2** indicates in which chapters of this thesis I addressed the study objectives outlined in my study protocol approved by the Faculty of Health Sciences Research Ethics Committee at the University of Pretoria.

**TABLE 2: Aims and objectives addressed in the chapters of the thesis.**

| | **Chapter 2** | **Chapter 3** | **Chapter 4** |
|---|---|---|---|
| **Aim** | | X | |
| **Objective 1** | X | X | |
| **Objective 2** | | | X |
| **Objective 3** | | X | |
| **Objective 4** | X | X | X |

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# CHAPTER 2

## Manuscript

Firstly, this chapter aims to provide an overview of the current literature on the epidemiology of figure skating injuries and associated injury risk factors. The chapter highlights the need for a more focused summary of the available evidence on injuries related to figure skating through a systematic review. The chapter covers the purpose of an updated systematic review and observes the findings of existing reviews. Lastly, this chapter will discuss ways to assess the risk of bias (RoB) in studies as well as provide more detail on relevant RoB tools to apply in the context of the study designs used in figure skating injury literature.

*In preparation for submission to: Sports*

Gaps in the knowledge on injuries related to figure skating and future research directions: A narrative review.

## 2.1 Narrative Review

### Submission detail

In preparation for submission to Sports.

### Title of submission:

Gaps in the knowledge on injuries related to figure skating and future research directions: A narrative review.

### Journal (ISSN):

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### Impact factor:

2.70 (2022)

# Gaps in the knowledge on injuries related to figure skating and future research directions: A narrative review.


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## Abstract

Figure skating is a physical activity known for being aesthetically and physically demanding. Over the years, the technical demand for the sport has increased, which may have increased injury risk. The purpose of this narrative review was to 1) provide an overview of the epidemiology of figure skating injuries and risk factors associated with injury in figure skating, 2) identify research gaps in the current literature, and 3) prioritise the future research needs in the field of figure skating related injuries. Three main data bases were searched using a search strategy. The prevalence of figure skating injuries is as high as 34%, while the incidence is 1.72 injuries per 1000 hours of ice training. Literature reports intrinsic and extrinsic risk factors for figure skating injuries. Currently, there are five other narrative reviews on figure skating injuries. There is no systematic review currently, on figure skating injuries and a large body of quantitative evidence which reports on the epidemiology of injury and injury risk factors in figure skating. A need exists to summarise this large body of evidence systematically and critically appraise the available body of evidence. This will provide researchers clarity on what is known and how to address future gaps in the literature. It will also assist clinicians with clinical decision-making in developing future risk management strategies.

## Keywords

Figure skating, epidemiology, risk factors, injury

## Introduction

Physical activity has shown to be beneficial in improving physical, mental, and cognitive health outcomes in children and adolescents (1). Physical activity has also been proven to reduce the risk of cardiovascular disease mortality and improve cognitive health, mental health, and sleep in adults (2). Unfortunately, physical activity is not without risk. One study estimated that 23 million adolescents experienced at least one serious injury per year in Africa (3). Figure skating is a type of physical activity known for being aesthetically and physically demanding (4). Over the years, the technical demand of the sport has increased, with skaters performing more intricate jumps, spins and lifts in order to obtain higher scores which may have resulted in an increased injury risk (4). Currently, there are several articles on the epidemiology of figure skating injuries and injury risk factors. A narrative review of these articles can provide context on the current available literature in figure skating on the epidemiology of injury and injury risk factors and further highlight the gaps in the current research providing researchers with a calculated direction for future work . The purpose of this review is to provide an overview on the epidemiology of figure skating injury and injury risk factors. This will indicate the current research gaps, allowing us to prioritise future research needs.

## Methods and materials

We searched through three main databases: Google Scholar, Web of Science and PubMed. The search was run in February 2022 and updated in August 2023. The search terms were divided into two main lists. The first described figure skating while the second described injury and risk factors. The first list consisted of the words ‘figure skat*”, “pair skating”, “ice dancing”, “single skating” and “synchronized skating”. The second list of words were “injur*”, “medical encounter”, “risk factor” and “epidemiology”. The first set and the second set of key words were combined with an OR operator followed by an AND operator. Title and abstracts were then screened for relevant articles. The included studies’ full texts were retrieved and if deemed relevant they were included for review. Studies which reported on epidemiology of injury and or injury risk factors were included. Case reports, case series, opinion-based, conference proceedings, commentaries, editorials, reviews, and studies only investigating biomarkers were excluded. The search was limited to studies published in English.

## Results

## Epidemiology and figure skating injury

*Prevalence of figure skating injuries*

Few studies reported injury prevalence (5, 6, 7, 8, 9). The highest prevalence noted was 34% (8). Only one of the studies reported injury prevalence during training (8), and only one reported injury prevalence in competition (9). The study that reported injury prevalence during training reported injury prevalence separately for lower extremity overuse conditions and did not report an overall injury prevalence. The study that reported the injury period prevalence during competition reported an overall injury

prevalence of 2.1% (9). This study collected data prospectively. However, 50% of the injury data occurring at the competition was only collected four to six weeks after the competition which may have led to recall bias. The study also had a short follow-up period (five days duration of the competition) (9). One of the other studies reported a one-year prevalence to be 31% for serve injury episode and 19% point prevalence for ongoing injury episode (7). This study was a cross-sectional study and only focused on single skaters (7). The two remaining studies focused on the prevalence of stress fractures. These two studies both reported an overall career prevalence, with one study reporting the prevalence of stress fractures in female figure skaters to be 16.7% and 13.3% for males (6), while the other study reported a prevalence of 24.4% for the entire population and 22.7% for females and 30.6% for males (5). Both studies' populations consisted of participants participating in single skating, pair skating and ice dancing, with the majority of the participants in both studies being single skaters (5,6). The main difference between the two studies was the study with the lower stress fracture prevalence focused on elite international level junior and senior figure skaters, while the study with the higher prevalence focused on novice to Olympic level participants. The study with the lower prevalence also had 644 participants while the study with the higher prevalence had 164 participants. Only one of the studies reported prevalence per discipline. This study reported the highest career prevalence for stress fracture in pair skating, followed by ice dancing and then single skating (6).

*Incidence of figure skating injury*

More studies reported injury incidence than prevalence (10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21). The incidence was reported inconsistently across the studies causing difficulty when comparing the values. Two studies focused on injury incidence during competition (17, 18). Engebretsen, et al., 2010 reported an injury incidence of 32 injuries per 1000 athletes (18), while Soligard, et al., reported 13.4 injuries per 100 athletes (17). Both studies were prospective studies which researched injuries and illness during the Winter Olympic Games (17,18). Both studies used medical encounters to collect data and had a very short follow up period (duration of the competition) (17,18). Although both the injuries incidences here are quite low, it is important to consider that the data in both these studies were collected using medical encounters at a high level of competition. This could have resulted in some of the injuries being missed as not all injured athletes would seek medical attention (22). None of the studies reported on injury incidence for training alone. Only one study reported the injury incidence in terms of injuries per 1000 exposure hours (1.37 per 1000 hours of training and 1.72 per 1000 hours of ice training) (13). This study followed a prospective study design and had a follow up period of 1 year. Unfortunately, this study only had eight participants who participated in single skating and was published in 1992 (13), only two years after figures had been removed from figure skating. Many studies that reported incidence did not report the incidence per discipline. One study that reported injury incidence over a twelve month period did report a slightly higher incidence in pair skating than ice dancing (0.5 & 0.4) (15). Another study that investigated the incidence of injury determined the highest incidence of injury per participant

in pair skating (0.32), followed by single skating (0.29) and then ice dancing (0.17) (12). A different study also reported a higher incidence proportion in pair skating than in ice dancing for overuse injuries but found a higher incidence in singles skating than pair skating for overuse injuries (20). Both studies were published in 2003 (12, 20). The first study used retrospective questionnaires and medical encounters to collect information about the athletes (12) while the second study only used a retrospective questionnaire (20). Only one study reported specifically on the incidence of injury in synchronized skating (14). This study reported an incidence proportion specifically for spinal conditions (14) making it difficult to compare to the other disciplines.

## Clinical characteristics of figure skating injuries

*Anatomical regions injured in figure skating.*

All studies identified reported on clinical characteristics of injury (4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34). Only one study reported anatomical regions and body areas injured specifically in training (8). This study specifically focused on lower limb overuse injuries during training (8). This study reported the knee, ankle and foot as injured body areas during training (8). Only one study reported an anatomical region and body areas injured during competition (9). This study reported the trunk as the only injured anatomical region in competition and reported injury only in the lumbosacral body area (9). The frequently reported anatomical region throughout all types of figure skating disciplines was the lower limb (4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 19, 20, 21, 24, 26, 27, 29, 30, 31, 33, 35) and trunk trunk (4, 5, 6, 9, 10, 11, 12, 13, 14, 15, 16, 19, 20, 24, 27, 28, 29, 30, 34). Frequently injured body areas were the knee (4, 5, 7, 8, 10, 11, 12, 13, 14, 15, 16, 19, 20, 21, 24, 26, 27, 29, 33), the foot (4, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 19, 20, 24, 26, 27, 30, 31) and the ankle (4, 5, 7, 8, 10, 11, 12, 13, 14, 15, 16, 19, 20, 24, 26, 27, 29, 30) (Figure 1). For single skating, pair skating and ice dancing frequently reported injured anatomical region was the lower limb. The trunk and the lower limb were frequently reported injured anatomical region for single skating. For pair skating, the lower and upper limbs were reported as frequently injured anatomical regions. Similarly, in ice dancing, the lower and upper limbs were reported frequently. The difference in frequency across body regions seen in single skating, pair skating and ice dancing may be owed to the difference and load and technique of each discipline. Only two studies reported injured anatomical regions and body areas separately for synchronized skating making all four body regions equally frequently reported.

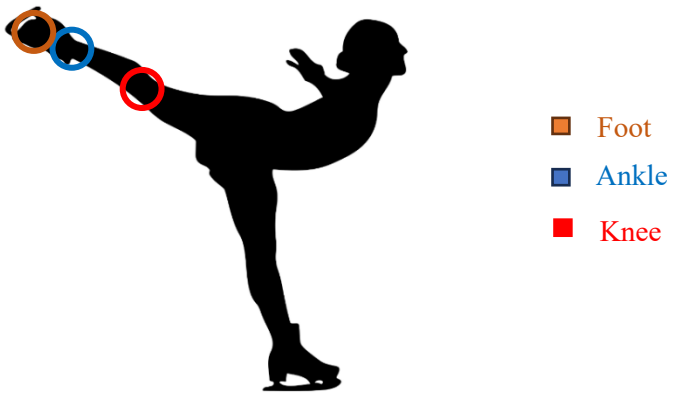


**FIGURE 1: Most frequently injured body areas across all disciplines of figure skating**

*Tissue and pathology types in figure skating*

Only one study specified tissue types and pathology types injured during training (8). This study only observed overuse conditions which may have affected the tissue and pathology types documented (8). This study reported muscle or tendon injuries, cartilage, synovium or bursa injuries, ligament or joint capsule and superficial or skin injuries as pathology types occurring in training (8). The most common diagnosis affecting skaters during training was retrocalcaneal bursitis followed by posterior heel skin callus and superficial calcaneal bursitis (8). Only one study reported on tissue types injured during competition and pathologies in competition (9). This study only reported muscle/tendon to be injured in competition and reported muscle cramping as the only pathology type. This study collected data prospectively and the follow up period was only for the duration of the competition (5 days) (9). This study only collected data through medical encounters (9). Overall bone (4, 5, 6, 10, 12, 13, 14, 15, 16, 19, 20, 21, 24, 26, 27, 28, 29, 30, 31, 33, 35), ligament and joint capsule (4, 8, 10, 12, 13, 14, 15, 16, 19, 20, 21, 24, 26, 27, 29) and muscle and tendon (4, 8, 9, 10, 12, 13, 15, 16, 19, 20, 21, 24, 27, 29, 33) injuries were commonly reported. For single skating, pair skating and ice dancing bone was a commonly reported tissue type (5, 6, 12, 20, 24). In single skating many studies reported bone and tendon or muscle (5, 12, 13, 20, 24) injuries. In pair skating bone was commonly reported together with ligament and joint capsule (12, 20, 24) and superficial or skin (12, 20, 24) injuries. Similarly, for ice dancing bone was commonly reported together with ligament and joint capsule injuries (12, 20). Unfortunately, only two studies reported on tissue types and pathology types affected by injuries in synchronized skating (10, 14). This resulted in an equal distribution in the number of studies that reporting all of the pathology types (10, 14) except muscle and tendon which was only reported by one of the two studies (10).

Muscle injury (12, 13, 24), tendinopathy (12, 13, 20), fractures (12, 20, 24), bone stress injuries (5, 6, 20) and joint sprains (13, 20, 24) were frequently reported pathology types in single skating. In pair skating, fractures (12, 20, 24), bones stress (5, 6, 20) injury and lacerations (12, 20, 24) were frequently reported pathology types. Two studies reported tendinopathy (12, 20), bone stress injury (5, 6) and

laceration (12, 20) in ice dancing. These pathology types were the most frequently reported pathology types.

## Risk Factors for injury in Figure skating

None of the identified studies specifically looked at risk factors in the context of competition participation. One study specifically collected data and reported risk factors for injury during a training related study (8). This study only looked at overuse lower limb injuries (8). This study identified two significant intrinsic risk factors, and two significant extrinsic risk factors (8). The intrinsic risk factors included increased age and increased body weight. An increased age significantly increased the risk for posterior heel skin callus in the contralateral foot and landing foot in non-elite skaters (8). Increased body weight significantly increased the risk for retrocalcaneal bursitis in the landing foot of non-elite skaters. In this particular study elite skaters referred to skaters that could do all the double jumps, a double axel, and one triple jump (8). The two significant extrinsic risk factors the study identified were ice time and boot-foot length difference. An increase in time on ice significantly increased the risk for lateral ankle skin abrasion in the contralateral foot and toe corns in the landing foot of elite skaters. An increased boot-foot length difference was associated with increased risk of superficial calcaneal bursitis in the landing foot of elite skaters and lateral ankle skin abrasion in the contralateral foot of elite skaters (8).

There was only one study which identified risk factors whose population solely consisted of single skaters. This study reported one significant intrinsic risk factor for single skaters and one significant extrinsic risk factors for single skaters (7). An increased age was associated with a severe injury episode as well as an ongoing injury episode (7). A severe injury episode in this study was defined as “any injury or pain that had occurred in connection with training or competition in figure skating, which resulted in more than 21 days of lost or altered participation in figure skating” (7) while an ongoing injury episode was defined as “an injury or pain that had occurred in connection with training or competition in figure skating, which prevented the skater from fully participating in training or competition at the survey time” (7). Similarly, an increased number of skipped meals lead to an increase in severe injury episodes and ongoing injury episodes (7). In a different study where participants only consisted of synchronized skaters only one intrinsic risk factor was identified (14). An increase in age was associated with increased risk for spinal problems in synchronized skaters.

Unfortunately, none of the other studies that identified risk factors had a population that only included one discipline or did not specify to which discipline the participants belonged. Overall, frequently investigated injury risk factors included training time and time spent on the ice (7, 8, 11, 34) together with age (7, 8, 14, 34), level of participation (5, 7, 14) and flexibility (8, 33). Significant extrinsic risk factors identified in other studies not previously discussed, included injury rates being higher in training

than in competition (17), and a training frequency of more than 12 sessions per week increased risk for sustaining a stress fracture (5).

## Research Gaps

Currently, there is a body of evidence on the epidemiology of figure skating injury and injury risk factors. Most of the studies seem to follow a cross-sectional study design. There are few studies which have followed a prospective study design, with some of these studies having a short follow up period and other studies having a long follow up period. All the studies with longer follow up period were published before 1997. Furthermore, there seems to be a lack of studies reporting injuries independently per discipline of figure skating. Currently, there are five reviews on figure skating injuries (36, 37, 38, 39, 40). All of the reviews identified were narrative reviews as none of the reviews provided any detail on the method used to identify studies or extract data. Further, none of these reviews attempts to limit the authors' bias throughout the review process. The currently available reviews provide a brief overview of the existing evidence. Two of the reviews highlighted the poor quality of evidence in currently existing literature but did not critically appraise or review the risk of bias of any of the included literature. The one review specifically noted a need to update resources found on Unites States figure skating (USFS) organisations as well as the International Skating Union (ISU) organisation when planning medical treatment of figure skaters (39). There is a need to evaluate the risk of bias in this body of literature, as there seems to be a perception of poor-quality research.

Further, there is a need for an unbiased summary of existing evidence which can assist in designing injury risk management strategies and further assist in new policy implementations, such as a resource update recommended by Lambrinakos-Raymond, et al. 2019 From the above narrative review, it is clear that there is a need for 1) an updated systematic review, on the epidemiology of figure skating injuries and injury risk factors 2) more prospective studies with a long follow up period which report injuries and risk factors independently per discipline and report on training and competition injuries and risk factors separately. Based on the available literature, we believe that completing the review before the prospective study will be beneficial. Completing a systematic review first will inform the researchers on how to improve the validity of their prospective studies by assessing the risk of bias in included studies. Prospective studies can then follow the systematic review.

## Types of systematic reviews

Systematic reviews can focus either on qualitative or quantitative data or be a mixed-method review, including both quantitative and qualitative data. All the studies identified in our narrative review collected quantitative data indicating that a planned systematic review would most likely be a quantitative systematic review.

## Risk of bias

The appraisal of available literature is an essential step in a systematic review. There has been a recent shift in research, and it is recommended to use the domain-based risk of bias assessment tools rather than quality assessment tools (41). Quality assessment tools only focus on the methodological rigor while the domain-based risk of bias focuses on how closely the study results represent the truth (41). Reporting the risk of bias per domain can inform readers how to improve future studies (42).

Currently, there are risk of bias tools that are widely used and recommended to assess risk of bias for intervention studies. However, there is a lack of evidence and guidance on assessing the risk of bias in observational studies (43). In a recent systematic review of quality assessment in prevalence studies, it was noted that none of the tools assessed could be strongly recommended and emphasised the importance of the development of a new tool which was domain-based and more applicable to observational studies. The study mentioned that the Joanna Briggs Institute Prevalence Critical Appraisal Tool had the highest methodological rigor (44), but as mentioned earlier, quality assessment only speaks to the methodological rigor and does not comment on the risk of bias, which is important when completing a systematic review. A recent article recommended the Quality In Prognosis Studies (QUIPS) tool to assess the risk of bias in prognostic factor studies (45). Higgins, et al initially designed the QUIPS. The QUIPS tool has six domains consisting of several signalling items that guide the assessor in a comprehensive assessment of each domain (46). It is recommended that the tool be operationalised before use and that reviewers define items that could result in systematic bias to improve assessment and consensus amongst reviewers (42). Several systematic reviews currently focus on the incidence, aetiology and risk factors of a particular sport have used the QUIPS tool to assess risk of bias (47, 48, 49, 50).When using the tool, a number of the studies used a certain percentage of “yes” responses to the signalling items of each domain to define whether the overall domain would be considered at high or low risk of bias (48, 50, 51). Although Higgins, et al recommended against the use of point system for a positive answer (52), Hayden, et al., later reported that consensus-based judgment requires knowledge on epidemiologic methods and further reported that it could be very challenging (46). They further recommended developing an online training tool to address this need (46).

## Limitations

Our search was limited to only three databases and made use of limited keywords. Due to limited keywords and few data bases used some relevant studies may have been missed. Additionally, the authors of this review are English and therefor our search was also limited to studies published in English which further may have resulted in important and relevant studies being missed.

## Conclusion

A large body of quantitative evidence currently reports on the epidemiology of injury and injury risk factors in figure skating. Few narrative reviews exist that highlight poor research quality but do not inform the reader in further detail on how this conclusion was drawn. There are currently no reviews on the epidemiology of figure skating injuries and injury risk factors which follow a systematic approach in identifying studies, extracting data or appraising the available literature using a risk of bias assessment tool. There is a need to summarise this available body of evidence systematically to create reliable results that can potentially assist in the creation of risk management strategies. There is no current evidence to support or recommend the use of a specific risk of bias assessment tool for observational studies. However, the QUIPS tool has been recommended for prognostic factor studies and has also been used for studies which look at incidence and risk factors.

## Author Contributions

1. Search and search strategy: Carel Viljoen & Natasha Schmidt
2. Composition of Results and Conclusion: Natasha Schmidt
3. Review of results and article: Natasha Schmidt, Carel Viljoen and Christa Janse van Rensburg

## Conflict of interest

The authors report no conflicting interest and declare no funding was received.

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## 2.2 Detail on next chapter

The next chapter will provide detail on the systematic review submitted to the Journal of Athletic Training. Chapter 3 is presented in the format of a manuscript submitted and formatted according to the specific journal's guidelines.

# CHAPTER 3

## Manuscript

*Submitted to Journal of Athletic Training:*

Schmidt N.T., Janse van Rensburg D.C., Schoeman M., Besomi M., Jansen van Rensburg A., Scheepers S., Garnett D., & Viljoen C. Epidemiology and associated injury risk factors in figure skating: a systematic review.

## 3. Manuscript

Following the identified need for a systematic review in the field of figure skating injuries and associated injury risk factors, I conducted a systematic review as lead author, working with a team. This chapter includes the details of the submitted manuscript and presents the full manuscript as submitted to the Journal of Athletic Training (Appendix A). For ease of reference, I have included the tables in relevant sections of the manuscript. These tables had to be submitted separately to the journal. I have also added the authors' names and initials throughout the manuscript to allow for easier review of this chapter. All identifiable details were removed from the submitted manuscript for the purpose of the journal's blinded peer-review process. Details of the abstract which was submitted to the seventh International Olympic Committee conference are also provided. `

### 3.1 Submission Details

**Tile of submission:**

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

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## 3.2 Abstract submitted for potential conference presentation

### Title:

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

### Conference:

7th IOC World Conference on Prevention of Injury and Illness in Sport

### Location:

Monte Carlo, Monaco

### Date:

29 February to 2 March 2024

### Type of presentation:

Poster

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

**Financial Disclosure and Conflict of Interest:**

All authors affirm that they have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript. All authors declare that there is no conflict of interest (i.e., personal associations or involvement as a director, officer, or expert witness).

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

**ABSTRACT**

**Objective:** To identify and critically appraise the available evidence on the epidemiology of injury and injury risk factors in figure skating.

**Design:** Systematic review.

**Data Source:** Eight databases were searched from inception to 28 April 2023 together with manual reference searching.

**Study Selection Criteria:** Studies reporting on the epidemiology of injury and/or investigated injury risk factors in figure skating.

**Data Extraction:** The included studies were distributed to four of the six authors for data extraction on a standardized data extraction sheet. One researcher extracted data from all included studies for quality control.

**Data Synthesis:** Twenty-eight studies were included. The prevalence range was 2.1%-34%, and the incidence, of injury was 1.72 per 1000 hours of ice training. The most frequently injured anatomical region was the lower limb, particularly the knee, foot and ankle with the most commonly reported pathology type being fractures and sprains. Significant intrinsic injury risk factors included an older age, previous history of stress fracture and a higher body mass. Significant extrinsic injury risk factors included training more than 12 sessions per week, skipping meals, hamstring and quadriceps immobility, training rather than competing, increased time on-ice time and boot-foot length difference.

**Conclusion** The incidence of figure skating injuries per 1000 hours was higher than in other artistic sports such as ballet. Overall, our review identified three significant intrinsic and eight significant extrinsic risk factors. More consistent data reporting and injury definitions is needed.

PROSPERO registration number: CRD42021293641

**Key words**: Figure skating, Injury, Risk factors, Epidemiology

**Abstract word count:** 247

**Body of manuscript word count:** 4402

**KEY POINTS**

- The knee, the foot and the ankle as the most commonly reported injured body areas.
- The most common pathology types reported were fractures, joint sprains and bone stress injuries.
- Three statistically significant intrinsic risk factors and seven extrinsic injury risk factors were identified through this review.
- There is currently a lack of literature specifically on the epidemiology of injury and injury risk factors for male figure skaters.

- The results from this review can assist in the design of injury risk management strategies in figure skating.

## INTRODUCTION

Figure skating is an artistic sport requiring strength, agility, power, and grace. The sport is governed by the International Skating Union (ISU) and divided into four disciplines; single skating, pair skating, ice dancing and synchronized skating[1]. Currently, the ISU has more than 90 members that are registered explicitly for figure skating worldwide[1].

Men and women participate separately in single skating which is characterised by the performance jump, spin elements, and a step sequence[2]. Pair skating is performed by men and women who skate side by side doing jumps, spins, lifts and throw jumps[2]. Ice dancing also consists of couples who perform together. However these skaters will not perform jumps and spins but instead focus on lifts, dance patterns and step sequences within a specific tempo and range[2]. Synchronized skating consists of a team of skaters who will perform intricate formations and step sequences[2].

The health benefits associated with physical activity are well-proven in children and adolescents[3](age 5-17) , however, the risk of injury and prevalence of injury should not be disregarded. Compared to other artistic sports such as ballet (1.24 injuries per 1000 dance hours) figure skating has a marginally higher injury incidence[4]. Figure skaters are exposed to high training loads with training up to 15 hours on ice with an additional 15 hours of off-ice per week[5]. Not only has figure skating grown in popularity worldwide[6] but, the technical demand of the sport has also increased[7]. A major change in the technical demand of the sport occurred in 1990 when compulsory figures were completely removed allowing more focus on a wide variety of jumps. Considering the escalated technical demand, the increased popularity of the sport, and the high training loads, the number of figure skaters presenting with injuries are predicted to increase[8].

Unfortunately, the research on figure skating injuries has not developed at the same pace, leaving little knowledge on the injury epidemiology and associated injury risk factors among these athletes[9]. Previous reviews have been published on figure skating injuries[6,8,10-12]. However, no systematic review has been conducted to systematically identify, review, and summarise the current evidence in context of the risk of bias of these published papers. Therefore, the research question of this study asks in context of risk of bias what the epidemiology of injury and associated injury risk factors in figure skating are?

The primary aim of this systematic review is to systematically identify, review, summarise and critically appraise all the currently available literature regarding the epidemiology of injury and the associated injury risk factors in figure skating. The purpose of this systematic review is to inform clinicians, such as physical therapists, with regards to the design of injury risk management strategies. In addition, this systematic review highlights the gaps in the current literature.

## METHODS

### Protocol Registration

We followed the 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines(Page et al., 2021), led by the PERSiST guidelines for implementing PRISMA in exercise, rehabilitation, sport medicine and sports science(Clare, Fionn, Renato, Adam, Maureen, Sinead et al., 2022). Our protocol for this systematic review was registered on PROSPERO (CRD42021293641) before the search was conducted.

### Study Selection 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 the ISU sanctioned the competition. The competition's website was consulted to clarify the eligibility if not clearly reported as an ISU sanctioned event. We considered all quantitative studies, but we excluded the following study designs: opinion-based papers, case reports, case series, conference proceedings, commentaries, editorials, reviews, and studies only investigating biomarkers of potential injury. 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, and only English language studies were considered for inclusion.

### 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(Roald, Ben, Wayne, Jiri, Carolyn, Caroline et al., 2020). The main outcome variables reported are the incidence of injury (rate: per 1000 hours 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 (such as odds ratio, prevalence ratio, risk ratio, risk difference p-values, correlation coefficients).

**Data 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 search was conducted from inception to 28 April 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 results of the first set of keywords were combined with an OR operator followed by the second set. Thereafter, an AND operator combined the two sets of keywords. The results were limited to studies published in English and only studies on the human population.

**Study Selection**

The identified studies were imported to EndNote 20 to identify and remove duplicates. Two researchers (NS & CV) independently screened the titles and abstracts for potential eligibility. Hereafter, two reviewers (NS & CV) again independently screened the selected full texts for eligibility. Any discrepancies in selection between the two reviewers were resolved via consensus. To ensure all potentially relevant studies were included, one reviewer (NS) screened the reference lists of all included studies.

**Data Extraction**

The final included studies were randomly allocated to four authors (CV, AJvR, MB, & DG) for data extraction, using a standardised data extraction sheet (Online supplementary appendix 2). The included studies were randomly distributed for data extraction. One researcher (NS) extracted data from all included studies for quality control.

The standardised 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) and body mass index (BMI, kg/m2).
- Epidemiology of injury: incidence of injury (rate: injuries/1000 figure skaters or injuries/ 1000 hours 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.

**Risk of Bias**

Risk of bias (RoB) was assessed using the QUIPS tool (quality in prognostic factor studies) [16,17]. Beforehand a meeting was held between NS and MS where each domain and signalling item of the QUIPS were discussed to ensure inter-rater reliability. NS and MS further optimised the tool for studies that did not report prognostic factors or follow a prospective study design with a follow-up period before use. The tool was optimised by the two authors agreeing that three of the six domains would not be relevant to these studies namely: study attrition, study confounding & prognostic factors. A pilot was run before the RoB assessment began. 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 signalling items of a domain, then the study's domain was ranked as low RoB. Scores of less than 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.

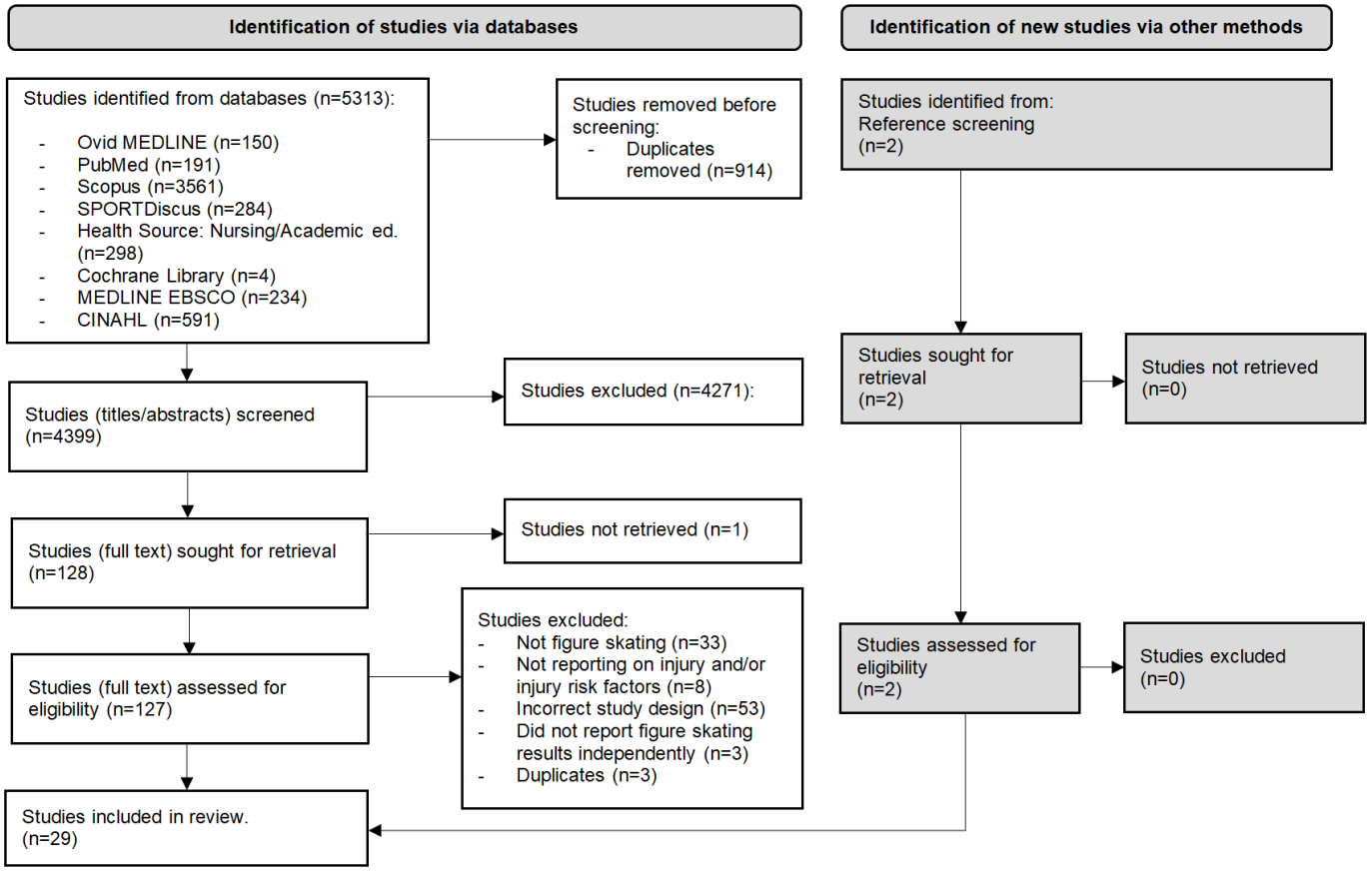
**Data Analysis**

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 and sudden vs gradual onset injuries. Where possible, the data were subdivided into various disciplines within figure skating. For the risk of bias section interrater reliability was calculated and presented as an observed agreement between reviewers (% of studies that obtained the same rating by both independent reviewers) prior to consensus. A kappa statistic was calculated for interrater reliability using the statistical software IBM SPSS version 28.0.1.0 (142).

**RESULTS**

Our initial search produced 5313 records, of which 914 were removed as duplicates (**FIGURE 1**). During the title and abstract screening, 4399 records were excluded. Screening of full text found 27 eligible articles 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.

**FIGURE 1: Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) 2020 Flow Diagram**



**Characteristics of all included studies**

The 29 included studies' publication dates ranged from 1979-2021. One study specifically focused on injury and/or injury risk factors in training exposure[18] (**TABLE 1**), while four focused on competition exposure[19-22]. The remaining studies did not specify if data were collected during a competition or training period[7,9,23-44]. Sixteen of the studies reported injury and/or injury risk factors for more than one discipline of figure skating[18,23-25,27,29-33,39-41,43-45], while eleven studies only defined the population as figure skaters and did not specify a discipline [7,9,19-22,26,34-37]. Most of the included studies investigated populations of North America [25,26,30-32,36,39-43], followed by Europe[9,18,33], Great Britain[23,24], and Asia[35]. All four studies that included competition exposure used injury definitions related to medical encounters[19-22], while ten studies used clinical assessment as well as self-reported data[18,26,31,33-36,39,43,44]. The remaining studies only used self-reported data[9,23-25,27-30,32,36-38,40-42 9,23-25,27-30,32,36-38,40-42]. Of all the included studies, four collected data prospectively with short follow-up periods (duration of the competition) [19-22] and four studies had longer term follow-up periods ranging from 9 months to 3 years [33,34,39,43]. Most studies (n=18) used cross-sectional study designs[9,18,23,24,26,28-32,35-38,40-42,44]. Seventeen of the eighteen studies that used cross-sectional study designs did not specify whether they investigated competition or training exposure[9,23,24,26,28-32,35-38,40-42,44] .

Ten included studies investigated injury risk factors[9,18,21,23,27,30,36,38,41,43] among a total of 2036 participants. Seven of the ten studies used cross-sectional designs[9,18,23,30,36,38,41] while two cohort studies collected data prospectively [21,43] One of the studies that collected data prospectively had a short follow-up period (duration of the competition)[21], while the other study had a follow-up period of longer than 1 year[43].

Our review included 4202 figure skaters, 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 6-79 years. Only five studies reported BMI [7,30,36,41,44].

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) and number of participants per discipline | Age (years) | Sex | BMI |
|---|---|---|---|---|---|---|---|
| Studies referring to Career Occurrence of injuries (not particularly training or competition based) | | | | | | | |
| Blewitt and Chockalingam (2011)[11] | Cross-sectional | Self-reported questionnaire | Online (Great Britain) | n=25 | 18-25yrs=7 participants<br>26-35yrs=12 participants<br>36-45yrs=3 participants<br>46-55yrs=1 participants<br>56-65yrs=1 participants<br>65+yrs =1 participants | Females n=23, Males n=2 | Not reported |
| Brown and Mckeag (1987)[7] | Cross-sectional | Self-reported questionnaire | Metropolitan Ice rink (United States of America) | n=14 (all pair skaters) | Males: Age range 15.2-21.6, Mean age 18.1<br>Females: Age range 12.8-16.0, Mean age 14.0 | Females n=7, Males n=7 | Not reported |
| Davis and Litman (1979)[13] | Cross-sectional | Medical interview & examination of athletes | Minneapolis (United Sates of America | n=45 | Age range 9-18, Mean age13.5 | Females n=45 | Not reported |
| Dubravcic-Simunjak *et al* (2008)[14] | Retrospective Cohort | Self-reported questionnaire | Online (International skating union members) | n=412<br>Junior Females: Single n=78, Pair n=12, Ice dance n=20<br>Senior Female: Single n=97 Pair n=16, Ice dance n=22<br>Junior Male: Single n=47 Pair n=12, Ice dance n=20<br>Senior Male: Single n=50 Pair n=16 Ice dance n=22 | Age range 12-25<br>Females: Median age 16,<br>Males: Median age 18 | Females n=245, Males n=167 | Not reported |

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| Dubravcic-Simunjak *et al* (2006)[15] | Cross-sectional | Self-reported questionnaire | Online (Teams participating in World synchronized skating Championship in 2004) | n=528 (all Synchronized skaters) | Female: Age range 15-28, Median age 19.4, Male: Age range 18-32, Median age 22.2 | Females n=514, Males n=14 | Not reported |
| Dubravcic-Simunjak *et al* (2003) [16] | Cross-sectional | Self-reported questionnaire | Junior world figure skating champion ships 1998, 2000, 2001, 2002 (Not specified) | n=469<br>Female single n=107<br>Female pair n=61<br>Female ice dance n=68<br>Males single n=104<br>Male pair n=61<br>Male ice dance n=68 | Age range 13-20, Females: Median age16, Males Median age 18 | Females n=236, Males n=233 | Not reported |
| King *et al* (2017)[27] | Cross-sectional | Self-reported questionnaire | Online & at Five United States Figure skating standardized tests 2011 (USA) | n=204<br>Single: NQ n=70, Q n=66, NI n=50<br>Pair: NQ n=3, Q n=4 NI n=15<br>Ice dance: NQ n=15, Q n=12, NI n=26<br>*NQ= Not qualified<br>NI= International<br>Q= Qualified | Average age 18.7±6.4, Age range NQ 7-37, Q 7-38, NI 12-37<br>*NQ= Not qualified<br>NI= International<br>Q= Qualified | Females n=90%, Males n=10% | Not reported |
| Naylor and Naylor (2021)[4] | Retrospective Cross-sectional | Self-reported questionnaire | Online (United Kingdom) | n=164<br>Single n=118, Pair n=19, Ice dance n=25, didn't Specify discipline n=2 | Mean age 28.3, Median age 28, Age range 8-79 | Females n=128, Males n=36 | Not reported |
| Okamura *et al* (2014)[33] | Cross-sectional | Medical check-ups by sports doctors & trained official association staff & a self - reported retrospective questionnaire | Japan sports association (Japan) | n=192<br>figure skaters n=33<br>speed skaters n=159 | Figure skaters: Mean age 14.6±1.8, Age range 12-18 | 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)[36] | Cross-sectional | Self-reported questionnaire, interview and | Universiad in Tatra Mountains 1987 & the gold pirouette in Zagreb 1987. (Not specified) | n=42 | Mean age 22.1 Age range 17-27 (at time of injury) | With stress fracture: Females | Not reported |

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| | | an analysis of medical reports | | | | n=5, Males n=4 | |
| Simunjak *et al* (2020) [41] | 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 synchronised skaters) | Junior skaters: mean age 16.23± 1.43, Median age 16, Age range 13-19<br>Senior skaters: Mean age 20.08±2.63, Median age 20, Age 15-30 | Females n=708 | Not reported |
| Smith and Micheli (1982)[43] | Cross-sectional | Self-reported questionnaire & clinical observation examination | Skaters who all trained at 1 rink (United States of America) | n=19 | Mean age 13.8, Age range 11-19 | Females n=15<br>Males n=4 | Not reported |
| Studies referring to injuries occuring over a 1-year period (not particularly training or competition based) | | | | | | | |
| Brock and Striowski (1986)[6] | Retrospective Cohort | Self-reported questionnaire | Not specified (Canada) | n=60<br>Single n=29, Pair n=13, Ice dance n=18 | Average age 18.8yrs | Female n=32 Male n=28 | Not reported |
| Ferrara and Hollingsworth (2007)[19] | Retrospective Cross-sectional | Self-reported questionnaire | Online, newsletter & US Adult Nationals 2005 (United Sates of America) | n=130<br>Single n=90%, Pair n=3%, Ice dance n=38%, Synchronized n=6%<br>* Some of the participants participated in more than 1 discipline* | Females: Average age 43 ± 9, Age range 34-52, Males: Average age 55±10, Age range 35-65 | Females n=113, Males n=17 | Average BMI for both men and women $18.5kg/m^2$<BMI<$25kg/m^2$ |
| Jederström *et al* (2021)[26] | Cross-sectional | Self-reported questionnaire | Online (Sweden) | n=137 | Mean age 12.9 | Females n=137 | Not reported |
| Kjaer and Larsson (1990)[28] | Prospective cohort | Weekly examination by physician & a questionnaire at year end | Not specified (Denmark) | n=8 (All single skaters) | Mean age 17, Age range 14-20 | Females n=5, Males n=3 | Not reported |
| Smith *et al* (1991) [44] | Prospective cohort | Examination | Single Camp held at Olympic training centre in Colorado Springs and Pair Camp at the University of Delaware in Newark (United States of America) | n=46 | Mean age 15.9, Age range 10-20 | Not reported | Not Reported |
| Studies referring to injuries that occurring over a 3-year period (not particularly training or competition based) | | | | | | | |

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| Kujala *et al* (1996)[30] | 3yr 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 | Athletic females: age range 10.3-13.3, mean age 11.7yrs, 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 age11.9 | 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)[29] | Retrospective chart review | Retrospective charts were review | Medical charts from regional paediatric sports medicine clinics (Not specified) | n=294 | Females: mean age 14.1 ±2.3 Males: mean age 15.3 ±2.0 | 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) [8] | Cross-sectional | Questionnaire, evaluation & scans | Not specified (not specified) | n=20: single n=11, pair n=3 ice dance n=6 | 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 | Females n=11, Males n=9 | Female Mean BMI 20.8 ± 1.7 Mean BMI Male 20.8 ± 1.7 |
| Fortin and Roberts (2003) [21] | Cross-sectional | Individual on-site evaluation and questionnaire | Not specified (United Sates of America) | n=208 Single n=90, Pair n=60 Ice dance n=58 | Age range 10-30yrs | Single Males: senior n=18, junior s 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: | Not reported |

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|---|---|---|---|---|---|---|---|
| | | | | | | senior n=18, junior n=12, Ice dance Males: senior n=15, junior n=14, Ice dance Females: Senior n=15, junior n=14 | |
| Oleson *et al* (2002)[34] | Cross-sectional – retrospective | Self-reported questionnaire, Interview and Bone sonometer | Tertiary care medical centre & 3 local skating clubs in Massachusetts (USA) | n=58 Figure skaters n=36 Control n=22 | 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 | 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)[42] | Prospective study | Examination and self-reported injuries | A single training centre & regional, sectionals, nationals & world championships (United States of America) | n=44 Pair n=16 teams, Ice dance n=8 teams | Average age 20.1, Age range 10.9-27.9 | 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)[47] | Cross-sectional | Self-reported questionnaire | Online (United States of America) | n=132 | Females: Mean age 16.8 ±3.0, Age range 10.0-22.0 | 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)[10] | Cross-sectional | Self-reported questionnaire, | Skating Clubs' Facilities (Italy) | n=76 Single n=85, Pair n=10 | Age range 6-33, Mean age 14.2±5.6 | Females n=75, Males | Not reported |

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| | | clinical examination & measurement of skater's equipment. | | | | n=20 | |
| Competition related studies | | | | | | | |
| Ruedl *et al* (2016)[39] | Cross-sectional | Medical encounters -by medical staff | Winter European Youth Olympic Festival in 2015 (Not specified) | n=899<br>Figure skaters n=48 | Mean age 17.1 ±0.8 | Figure skating females n=30<br>Figure skating males n=18 | Not reported |
| Ruedl *et al* (2012)[40] | Cross-sectional | Medical encounters -by medical staff | First Winter Youth Olympic Games in Innsbruck-Austria in 2012 (Not specified) | n=1021<br>Figure skaters n=66 | Mean age 16.6±0.9 (all participant's) | Figure skating: females n=33, male n=33 | Not reported |
| Soligard et al (2015)[46] | Prospective | Medical staff - medical encounters | Sochi at 2014 Winter Olympic Games (Not specified) | n=2788<br>Figure skaters n=149 | Not Reported | Figure skating Female n=74,<br>Figure skating Male n=75 | Not reported |
| Engebretsen *et al* (2010)[18] | Prospective | Medical encounters | XXI Winter Olympic Games 2010 (Not Specified) | n=2567<br>Figure skaters n=146 | Not reported | Figure skating Females n=73,<br>Figure skating Males n=73 | Not reported |

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**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[18-20 22 29 9 7 36 38].

Sixteen of the included studies scored a moderate rating for "study participation" domain[20,21,23,25-27,30,31,35-41,43]. Most studies rated moderate or high RoB for the signalling items "period of recruitment", "place of recruitment" and "inclusion and exclusion criteria". These ratings were due to vague or absent reporting on period and place of recruitment. 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 signalling 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 which resulted in a partial rating for the second signalling 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[9,18,19,21,23,27,30,34-36,38,41,43] where domain 5 could be rated, eleven[9,19,21,30,34,35,38,43] did not account for important confounders resulting in a high RoB for this domain. In domain 6, many studies did not follow a recognised conceptual framework or model[21,23,27,29,31-37,40] **(TABLE 2)**

**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 (2021)[4] | Moderate | NA | Moderate | Moderate | High | Moderate |
| Blewitt & Chockalingam (2011) [11] | High | NA | NA | Moderate | NA | Moderate |
| Brock & Striowski (1986)[6] | Moderate | NA | NA | Moderate | NA | Moderate |
| Brown & McKeag (1987)[7] | High | NA | NA | Moderate | NA | High |
| Burt *et al* 2021[8] | Moderate | NA | NA | NA | Moderate | Low |
| Campanelli *et al* (2015)[10] | Low | NA | Low | Moderate | High | Low |
| Davis & Litman (1979)[13] | Moderate | NA | NA | Moderate | NA | High |
| Dubravcic-Simunjak *et al* (2008) [14] | Moderate | NA | Moderate | Moderate | High | Moderate |
| Dubravcic-Simunjak *et al* (2006) [15] | Low | NA | NA | Moderate | NA | Moderate |
| Dubravcic-Simunjak *et al* (2003) [16] | Low | NA | NA | Moderate | NA | Low |
| Engebretsen *et al* (2010)[18] | Low | NA | NA | Moderate | NA | Low |
| Ferrara and Hollingsworth (2007)[19] | Moderate | NA | Moderate | Moderate | High | Moderate |
| Fortin and Roberts (2003)[21] | Moderate | NA | NA | Moderate | NA | Moderate |
| Jederström *et al* (2021)[26] | Low | NA | Moderate | Moderate | High | Low |
| King *et al* (2017)[27] | High | NA | NA | High | NA | Moderate |
| Kjaer and Larsson (1992)[28] | High | Low | NA | Moderate | NA | High |
| Kowalczyk *et al* (20210[29] | Low | NA | NA | Moderate | NA | Low |
| Kujala *et al* (1996)[30] | High | Moderate | Moderate | Moderate | High | Moderate |
| Okamura *et al* (2014)[33] | Moderate | NA | Low | Moderate | High | Moderate |
| Oleson *et al* (2002)[34] | Moderate | NA | Moderate | Moderate | Moderate | Low |
| Pecina *et al* (1990)[36] | Moderate | NA | NA | Moderate | NA | High |
| Ruedl *et al* (2016)[39] | Low | NA | Moderate | Moderate | High | Low |
| Ruedl *et al* (2012)[40] | Moderate | NA | NA | Low | NA | Low |
| Simunjak *et al* (2020)[41] | Moderate | NA | Moderate | Moderate | High | Low |
| Smith & Ludington (1989)[42] | Moderate | Low | NA | Moderate | NA | Moderate |
| Smith & Micheli (1982)[43] | Moderate | NA | NA | High | NA | High |
| Smith *et al* (1991)[44] | Moderate | High | Moderate | Moderate | High | Moderate |
| Soligard *et al* (2015)[46] | Moderate | NA | Moderate | Moderate | High | Moderate |
| Sugimoto *et al* (2020)[47] | Moderate | NA | Moderate | Moderate | Moderate | Moderate |

NA: Not Applicable

**Epidemiology of Injury**

Five included studies reported injury prevalence[9,18,19,23,27]. One of the studies reported injury prevalence during training[18], and only one reported injury prevalence in competition[19]. The prevalence range was 2.1%-34%[18,19]. The study that reported the lowest period prevalence collected data prospectively and had a short follow-up period (duration of the competition)[19]. The study that reported the highest prevalence of injury collected data using a questionnaire together with a clinical assessment which focused on prevalence of overuse injuries[18]. Twelve of the included studies reported injury incidence[21,22,24,25,28-31,33,38-40]. Two of these studies focused on injury incidence specifically in competition[21,22]. Only one study reported the injury incidence per 1000 exposure hours (1.37 injuries per 1000 total training hours[33]) (Online supplementary appendix 3).

**Anatomical Region and body area**

All 29 included studies documented on clinical characteristics of injury[7,9,18-43]. Lower limb[7,9,18,23-33,35-40,42-44] (n=23, 79%) and trunk[7,19,23,24,27-36,38-42] (n=19, 66%) injuries were reported by most studies, followed by upper limb injuries (n=13, 45%)[7,23,24,28-31,33,36,38-40,42](**TABLE 3**). The body area most commonly reported was the knee (n=19, 66%) [7,9,18,23-26,28-33,35,38-40,42,43] followed by both the foot [7,9,18,23,24,26-33,36,37,39,40,42] and ankle [7,9,18,23,24,26,28-33,35,36,38-40,42] (n=19, 66%) and then, the lumbosacral area [7,19,23,27-29,31-36,38-42] (n=17, 59%) (Online supplementary appendix 3).

232 **TABLE 3: Summary of the number of studies (n) reporting injury variables regarding the anatomical region and body area**

233

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| Anatomical Region | Body Area | All studies (n=28) | Competition related studies | Training Related studies | Single skating | Pair skating | Ice dancing | Synchronized skating |
|---|---|---|---|---|---|---|---|---|
| Head & Neck | All | 11 [6, 7, 11, 15, 16, 19, 21, 27, 41-43] | - | - | 1[7] | 3[7, 16, 21] | 1[16] | 2[15, 41] |
| | Head | 11[6, 7, 11, 15, 16, 19, 21, 27, 41-43] | - | - | 1[7] | 2[7, 16] | 1[16] | 2[15, 41] |
| | Neck | 4 [11, 15, 21, 41] | - | - | - | 1[21] | - | 2[15, 41] |
| Upper Limb | All | 13 [4, 7, 11, 15, 16, 19, 21, 28, 29, 34, 41-43] | - | - | 4[4, 7, 16, 21] | 4[4, 7, 16, 21] | 3[4, 16, 21] | 2[15, 41] |
| | Shoulder | 10 [7, 11, 15, 16, 19, 21, 29, 41-43] | - | - | 1[21] | 3[7, 16, 21] | 1[21] | 2[15, 41] |
| | Upper Arm | 2 [7, 15] | - | - | 1[7] | - | - | 1[15] |
| | Elbow | 3 [7, 15, 21] | - | - | 1[7] | 1 [21] | 1[21] | 1[15] |
| | Forearm | 2 [15, 41] | - | - | - | - | - | 2[15, 41] |
| | Wrist | 12 [4, 7, 11, 15, 16, 19, 21, 29, 34, 41-43] | - | - | 1[4, 21] | 3[4, 7, 16] | 3[4, 16, 21] | 2[15, 41] |
| | Hand | 7[15, 16, 19, 21, 28, 42, 43] | - | - | 1[28] | 2[16, 21] | - | 1[15] |
| Trunk | All | 19[4, 7, 11, 14-16, 19, 21, 27-30, 33, 34, 39, 41-43, 47] | 1[39] | - | 6[4, 7, 14, 16, 21, 28] | 2[7, 21] | 2[4, 21] | 2[15, 41] |
| | Chest | 3 [23,43 7] | - | - | - | 1[7] | - | - |
| | Thoracic spine | 4[7, 15, 29, 41] | - | - | 1[7] | - | - | 2[15, 41] |
| | Lumbosacral | 17[4, 7, 14-16, 21, 27-30, 33, 34, 39, 41-43, 47] | 1[39] | - | 5[4, 7, 14, 16, 28] | 1[16] | 1[16] | 2[15, 41] |
| | Abdomen | 1 [15] | - | - | - | - | - | 1[15] |
| Lower Limb | All | 23[4, 6-8, 10, 11, 13-16, 19, 21, 26-29, 33, 34, 36, 41-44] | - | 1[10] | 6[4, 7, 14, 16, 21, 28] | 5[4, 7, 14, 16, 21] | 4[4, 14, 16, 21] | 2[15, 41] |
| | Hip/groin | 10[7, 11, 15, 16, 19, 21, 26, 29, 42, 43] | - | - | 3[7, 16, 21] | 3[7, 16, 21] | 2[16, 21] | 1[15] |
| | Thigh | 7[11, 15, 16, 29, 33, 42, 43] | - | - | 1[16] | 1[16] | - | 1[15] |
| | Knee | 19[4, 6, 7, 10, 11, 13, 15, 16, 19, 21, 26-29, 33, 41-44] | - | 1[10] | 4[4, 7, 16, 21] | 2[16, 21] | 2[4, 21] | 2[15, 41] |
| | Lower leg | 13 [4, 7, 11, 14-16, 27-29, 34, 36, 42, 43] | - | - | 4[4, 14, 16, 28] | 4[4, 7, 14, 16] | 1[21] | 1[15] |
| | Ankle | 18[4, 7, 10, 11, 13, 15, 16, 19, 21, 26-29, 33, 34, 41-43] | - | 1[10] | 5[4, 7, 16, 21, 28] | 1[16] | 2[4, 16] | 2[15, 41] |
| | Foot | 18[4, 7, 10, 11, 13-16, 19, 21, 26-29, 34, 36, 42, 43] | - | 1[10] | 6[4, 7, 14, 16, 21, 28] | 2[14, 16] | 2[4, 21] | 1[15] |

**Tissue Type and Pathology type**

Bone was the tissue type most reported (n=21, 72%) [7,23-29,31-40,42-44], followed by both muscle/tendon[7,18,19,24,25,28,29,31-33,35,39,40,42,43] and ligament and joint capsule[7,18,24-26,28,29,31-33,35,38-40,42] (n=15, 52%) (**TABLE 4).** The most commonly reported pathology types was, fractures (n=15, 52%)[7,23-25,28,29,32,34-36,38-40,42 44], joint sprains (n=14, 48%) [7,18,24-26,28,29,32,33,35,38-40,42] followed by bone stress injuries (n=13, 45%)[7,23,26-29,32,35-38,40,44]. Tendinopathies were reported in 11 (38%) of studies[18,25,28,29,31-33,35,39,40,43] (Online supplementary appendix 3).

**TABLE 4: Summary of the number of studies (n) reporting injury variables regarding tissue and pathology type**

| Tissue Type | Pathology Type | All studies | Competition related studies | Training related studies | Single skating | Pair skating | Ice dancing | Synchronized skating |
|---|---|---|---|---|---|---|---|---|
| Muscle/Tendon | All | 15[6, 7, 10, 11, 15, 16, 21, 27-29, 33, 39, 42-44] | 1[39] | 1[10] | 5[4, 7, 16, 21, 28] | 2[16, 21] | 2[16, 21] | 1[15] |
| | Muscle injury | 8[7, 21, 27-29, 33, 42, 43] | - | - | 3[7, 21, 28] | - | 1[21] | - |
| | Muscle cramping | 2[7, 39] | 1[39] | - | 1[7] | - | - | - |
| | Muscle Compartment syndrome | 1[11] | - | - | - | - | - | - |
| | Tendinopathy | 11[6, 10, 15, 16, 21, 27, 28, 33, 42-44] | - | 1[10] | 3[16, 21, 28] | 2[16, 21] | 2[16, 21] | 1[15] |
| | Tendon Rupture | 2 [29, 43] | - | - | - | - | - | - |
| Nervous | All | 10[7, 11, 15, 21, 27-29, 41-43] | - | - | 1[7] | 1[7] | - | 2[15, 41] |
| | Brain(concussion) | 7[7, 11, 15, 27, 41-43] | - | - | 1[7] | 1[7] | - | 2[15, 41] |
| | Peripheral Nerve Injury | 5[15, 16, 21, 28, 29] | - | - | 2[16, 21] | 1[16] | - | 1[15] |
| Bone | All | 21 [4, 6-8, 11, 13-16, 21, 27-30, 33, 34, 36, 41-44] | - | - | 5[4, 7, 14, 16, 21] | 5[4, 7, 14, 16, 21] | 3[4, 14, 16] | 2[15, 41] |
| | Fracture | 15[4, 6, 7, 11, 15, 16, 27, 29, 30, 33, 34, 41-43 8] | - | - | 3[7, 16, 21] | 3[7, 16, 21] | 1[16] | 2[15, 41] |
| | Bone stress injury | 13[4, 8, 13-16, 27, 29, 33, 34, 36, 41, 43] | - | - | 3[4, 14, 16] | 3[4, 14, 16] | 2[4, 14] | 1[15, 41] |
| | Physis Injury | 1 [29] | - | - | - | - | - | - |
| | Periosteal injury | 7[13, 15, 16, 29, 44 28, 33] | - | - | 1[16, 28] | 1[16] | 1[16] | 1[15] |
| Cartilage/ Synovium/Bursa | All | 12[6, 10, 11, 15, 16, 19, 21, 28, 29, 41, 42 43] | - | 1[10] | 2[16, 28] | 1[21] | 1[21] | 2[15, 41] |
| | Cartilage Injury | 7[6, 11, 21, 28, 29, 41, 42] | - | - | 1[28] | 1[21] | 1[21] | 1[41] |
| | Arthritis | 2[11, 19] | - | - | - | - | - | - |
| | Synovium, capsulitis | 3[15, 16, 29] | - | - | 1[16] | - | - | 1[15] |
| | Bursitis | 5[10, 21, 29, 42, 43] | - | 1[10] | 1[21] | - | | |
| Ligament/ Joint Capsule | All | 15[6, 7, 10, 11, 13, 15, 16, 21, 27-29, 33, 41-43] | - | 1[10] | 3[16, 21, 28] | 3[7, 16, 21] | 2[16, 21] | 2[15, 41] |
| | Joint sprain | 14[6, 7, 10, 11, 13, 15, 16, 27-29, 33, 41-43] | - | 1[10] | 3[7, 16, 28] | 1[16] | 1[16] | 2[15, 41] |
| | Joint dislocation | 3[7, 16, 29] | - | - | - | 2[7, 16] | - | - |
| | Chromic Instability | 1[29] | - | - | - | - | - | - |
| Superficial/ Skin | All | 13[7, 10, 11, 13, 15, 16, 19, 21, 27, 29, 41-43] | - | 1[10] | 2[7, 21] | 3[7, 16, 21] | 2[16, 21] | 2[15, 41] |
| | Contusion | 9[11, 15, 19, 21, 27, 29, 41-43] | - | - | 1[21] | 1[21] | 1[21] | 2[15, 41] |
| | Hematoma | 4[7, 15, 29, 43] | - | - | 1[7] | 1[7] | | 1[15] |
| | Callus | 1[10] | - | 1[10] | - | - | - | - |

| Tissue Type | Pathology Type | All studies | Competition related studies | Training related studies | Single skating | Pair skating | Ice dancing | Synchronized skating |
|---|---|---|---|---|---|---|---|---|
| | Corns | 2[10, 13] | - | 1[10] | - | - | - | - |
| | Bunion | 1[13] | - | - | - | - | - | - |
| | Laceration | 11[4, 7, 11, 14-16, 21, 29, 41-43] | - | - | 2[7, 21] | 3[7, 16, 21] | 2[16, 21] | 2[15, 41] |
| | Abrasion | 1[10] | - | 1[10] | - | - | - | - |
| | Skin Irritation | 1[10] | - | 1[10] | - | - | - | - |

### 4.6 Injury risk Factors

The most frequently investigated injury risk factors included training time and time spent on the ice[9,18,30,41] followed by age[9,18,38,41], level of participation[9,23,38] and flexibility[18,43]. Significant intrinsic risk factors reported include; being older in age increased the risk for severe injury episodes (OR 1.2, 95% CI 1.1-1.4, p=0.002)[9], ongoing injury episodes (OR 1.4, 95% CI 1.2-.17 p<0.001)[9] lower back injuries(OR =1.211, 95% CI 1.058-1.3686, p=0.005)[41], spinal condition ($\chi^2$=12.602, df=1, p=0.0004)[38] 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[18]. 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)[18]. 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)[23]. 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)[21], a training frequency of more than 12 sessions per week increased risk for sustaining a stress fracture (RR:1.875, 95% CI 1.08-3.25, p= 0.028)[23] and an increased number of skipped meals per week increased the risk for a severe injury episode (OR: 1.1, 95% CI 1.0-1.3, p=0.014)[9] and an ongoing injury episode (OR: 1.1, 95% CI 1.0-1.3, p=0.049)[9] (**TABLE 5**).

**TABLE 5: 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 | - | $1^{4}$ | - | - | - | 1 |
| Previous history of stress fracture | $1^{4}$ | - | - | - | - | 1 |
| Increased Age | $3^{26, 41, 47}\zeta\theta\varpi$ | - | - | - | - | 3 |
| Increased Age | $1^{10}\ \alpha$ | $1^{10}\ \beta$ | $1^{10}\ \chi$ | - | - | 1 |
| Higher Body weight | $1^{10}\ \delta$ | - | - | - | - | 1 |
| Not reaching Menarche | - | $1^{14}$ | - | - | - | 1 |
| Extrinsic injury risk factor | | | | | | |
| Training frequency | $1^{4}$ | - | - | - | - | 1 |
| Level of participation | - | $2^{4, 26}$ | - | - | - | 2 |
| Boot-foot length difference | $1^{10}\ \psi\ \varepsilon$ | $1^{10}\ \phi$ | $1^{10}\ \gamma$ | - | - | 1 |
| On ice time | $1^{10}\ \eta$ | $1^{19, 47}$ | - | $1^{10}\ \varepsilon$ | - | 3 |
| Jump Height | - | $1^{10}\ \delta$ | $1^{10}\ \varphi$ | $1^{10}\ \phi$ | - | 1 |
| Ankle Flexibility | - | $1^{10}\ \delta$ | $1^{10}\ \kappa$ | $1^{10}\ \lambda$ | - | 1 |
| Bendability Score | - | - | $1^{10}\ \mu$ | $1^{10}\ \pi$ | - | 1 |
| Foot arch index | - | - | - | $1^{10}\ \varepsilon$ | - | 1 |
| Not reaching menarche | - | - | - | - | $1^{14}$ | 1 |
| Stretching & warming up | - | - | - | - | $1^{19}$ | 1 |
| Number of hours spent skating | - | $1^{47}$ | - | - | $1^{19}$ | 2 |
| Skipped meals | $1^{26}\theta\varpi$ | - | - | - | - | 1 |
| Mean weekly training hours of 7-12hr | - | $1^{26}\ \theta$ | - | $1^{26}\varpi$ | - | 1 |
| Mean weekly training hours of >13 | - | $1^{26}\varpi\ \theta$ | - | - | - | 1 |
| Quadriceps-inhibited flexion angle of 35 degrees | $1^{44}$ | - | - | - | - | 1 |
| Quadriceps-inhibited flexion angle of 14 degrees | | - | $1^{44}$ | - | - | 1 |
| Hamstring immobility | $1^{44}$ | - | - | - | - | 1 |
| Resistance training | | - | - | $1^{47}$ | - | 1 |
| Training rather than competition | $1^{46}$ | - | - | - | - | 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

## DISCUSSION

To our knowledge, this is the first systematic review that focuses on the epidemiology and associated risk factors of injury in figure skating. The injury prevalence range in figure skating is 2.1%-34%[18,19], with only one study reporting the injury incidence per 1000 exposure hours (1.37 injuries per 1000 total training hours[33]). Currently, the lower limb is reported as the most injured anatomical site (n=23, 79%)[7,9,18,23-33,35-40,42-44], mainly affecting the knee (n=19, 66%) [7,9,18,23-26,28-33,35,38-40,42,43]. The most injured tissue type is bone (n=21, 72%) [7,23-29,31-40,42-44], with fractures reported as the most injured pathology type (n=15, 52%)[7,23-25,28,29,32,34-36,38-40,42]. Our systematic review identified 11 risk factors that are significantly associated with injury among figure skaters (three intrinsic and seven 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 designs, data collection procedures, injury definitions and populations.

### Injury definition and data collection

None of the included studies defined injury according to the 2020 IOC consensus statement of recording and reporting injuries in sport[15]. Some of the included studies did not clearly define injury while other studies used clinical examination by a medical professional to diagnose injury. Some studies used medical attention to define injury. Several studies used time loss to define injury which may lead to an under-estimation of injury and the burden of injury. The studies also varied in the number of days used to define injury ranging from one day to more than 21 days.

Ten of the 29 included studies collected data via retrospective self-reported questionnaires. Retrospective self-reported injury data is often unreliable and likely to be inaccurate[46]. Athletes are often unable to define specific details of the injury and the diagnosis, resulting in underreporting of injuries[46]. Only one included study utilized a long follow-up period.

### Incidence and prevalence

Only one study reported the injury incidence in terms of injuries per 1000 exposure hours (1.37 per 1000 hours of training and 1.72 per 1000 hours of ice training)[33]. This study only had eight participants whom all participated in single skating[33]. 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%)[22]. However, the physical demands of these sports largely differ from figure skating. Compared to other artistic sports such as ballet (1.24 injuries per 1000 dance hours) figure skating has a marginally higher injury incidence[4]. Limited studies report the injury incidence per figure skating discipline, and they reported conflicting results[29,31]. Pair skating had the

highest injury incidence followed by single skating and ice dancing among competitive American figure skaters that considered all injuries[31]. 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[29]. Given the limited literature and contrasting findings, we cannot make any concrete differentiation between injury incidence for different figure skating disciplines.

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 followed by clinical examination[18], while the lower injury prevalences were documented for injuries requiring medical attention at an elite youth event[19]. Recording only medical attention injuries could 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%[9].

**Clinical characteristics**

The most injured anatomical region was the lower limb (79%), followed by the trunk and the upper limb. Lower limb and trunk injuries were the most frequently injured anatomical regions in single skating. In comparison the lower limb and upper limbs were the most injured anatomical region in pair skating and ice dancing. Upper limb injuries may be more frequently reported in pair skating and ice dancing since the nature of these two disciplines include 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 potential delayed impaired cognitive function and mental health [47].

The most frequently injured tissue type reported was bone, while the most 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 manoeuvres results in blunt trauma onto a hard ice surface and usually at high velocities.

**Significant injury risk factors**

The most reported injury risk factor was age. Older age was associated with a severe injury episode, ongoing injury episode and increased risk of sustaining a lower back injury[9,41]. Being older was also associated with an increased risk of sustaining a posterior heel skin callus in the landing foot and the contralateral foot in non-elite skaters[18]. In contrast, being younger was associated with an increased risk of sustaining superficial calcaneal bursitis in the contralateral foot in elite skaters[18]. The study design

and data collection procedure should be considered. All three studies that reported age as a risk factor had a cross-sectional study design[9,18,41]. The first two studies only made use of a retrospective questionnaire to collect data[9,41]. The third study used a questionnaire, and clinical exam and measured the skater and their equipment[18]. All three studies performed a multivariate analysis. At the Olympic Games a higher risk for injury was reported during training than in competition[21]. The author followed a prospective study design and collected medical encounters, however the participants were only followed for the duration of the competition[21]. Another study also reported that training 12 or more sessions per week increased their risk for stress fracture[23]This same study reported that 44.4% of the participants trained more than 12 sessions a week[23]. Another study reported that the average number of training sessions per week for pair skaters was 17.4 sessions a week[42]. 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 be translated into sessions per week accurately. Increased on-ice time significantly increased the risk for lateral ankle skin abrasion in the contralateral foot in elite skaters[18]. The included studies reported a wide variety of skating hours per week which ranged from 4-21 hours per week. Skipping a meal was also a significant risk factor for a severe and ongoing injury[9]. 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 jumpers' 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[43].

**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 the English language. Even though most sports injury literature is published in English, we may have excluded a relevant article published in a different language. Performing a meta-analysis was not possible due to the heterogeneous nature of the included studies. 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 of figure skating could have exposed figure skaters to different injuries and contributors to injury risk.

Five of the included studies[23,27,36,37,45] only focused on reporting injuries related to stress fractures and/or acute fractures. This may have contributed to bone being reported as the most injured tissue type and fractures as the most injured pathology type.

## Clinical Implication

This review identified three intrinsic and seven extrinsic significant injury risk factors. For these factors to be useful, it needs to be implemented in context of the specific injury regions and pathologies. Therefore, to assist physical therapists with informed decision-making regarding the design of injury risk management strategies, we reported on the clinical characteristics of injury as well. We recommend that physical therapists consider the context of the individual figure skater during the design and implementation of these risk management strategies.

## 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[15] and use a recognised framework when reporting injury data. This will allow for the comparison of data collected across various studies. Future researchers should also consider validating questionnaires. When investigating risk factors, researchers need to be cognisant of how complex the process is, and future researchers should ensure that all confounders are considered to avoid a reductionist approach to risk factor assessment. Further, more information is needed on the epidemiology of injury and injury risk factors per discipline rather than across figure skating. The nature of these disciplines varies, and they are exposed to vastly different loads. The limited research currently available shows different injury patterns and potentially different injury incidences and prevalence. However, more data will be needed to provide insight for medical professionals caring for these athletes. Most of the population in the available data consisted of female figure skaters, more research is needed on male figure skaters as the injury patterns will differ from female figure skaters especially in disciplines such as pair skating and ice dancing, where their role is entirely different to female skaters.

# CONCLUSION

The most frequently injured anatomical region in figure skating was the lower limb, specifically the knee, foot, and ankle. Being older was the most frequent and well-researched risk factor for identified injuries. Our review identified three significant intrinsic and seven significant extrinsic risk factors. Good quality research investigating figure skating injuries and injury risk factors is scarce Overall more consistent data following a recognised framework and injury definitions are needed. Advances in figure skating injury and injury risk factor research will aid in developing and implementing injury prevention strategies allowing safer partcipation in the sport.

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# CHAPTER 4

## Discussion

This chapter consists of a discussion, clinical and research recommendations, final limitations, and concluding statements.

## 4. Discussion

We conducted the first systematic review on the epidemiology of injury and associated injury risk factors in figure skating. The narrative review in chapter two highlighted the need for a systematic review, completed in chapter three. This systematic review identified 29 studies investigating injury and/or injury risk factors in figure skating, since 1979 to 2021. When considering the findings of this systematic review, it is important to consider that a large majority of the studies included data collected retrospectively and with a cross-sectional study design. Only eight of the included studies followed a prospective study design with a follow-up periods ranging from 9 months to 3 years , Eight of the included studies were conducted before or in 1990 (Davis et al., 1979; Smith et al., 1982; Brock et al., 1986; Brown et al., 1987; Smith et al., 1989; Pećina et al., 1990; Kjaer et al., 1992; Kujala et al., 1996) when a major rule change occurred which resulted in more focus being placed on jumps. Most of the participants in the included studies were female (74%). Many studies used time loss to define injury, with a great variation in the number of days required to define injury. Other studies used medical encounters, and none used the International Olympic Committee (IOC) consensus statements which guide recording and reporting epidemiological data in sport. This review also included five studies (Andrew Naylor et al., 2023; Dubravcic-Simunjak et al., 2008; Oleson et al., 2002; Pećina et al., 1990; Burt et al., 2022b) which only focused on reporting injuries related to stress fractures and/or acute fractures which may have influenced the high number of bone injuries recorded.

The four disciplines of figure skating vary in required elements for competitions which could result in variation in load exposure amongst skaters in these disciplines. Many of the studies have a population comprising a mix of figure skating disciplines. Unfortunately, these studies do not report injury independently per discipline and some only define participants as figure skaters (Andrew Naylor et al., 2023; Blewitt, 2011; Brock et al., 1986; Burt et al., 2022b; Davis et al., 1979; Engebretsen et al., 2010; Ferrara et al., 2007; King et al., 2017; Kjaer et al., 1992; Kowalczyk et al., 2021; Kujala et al., 1996; Okamura et al., 2014; Oleson et al., 2002; Pećina et al., 1990; Ruedl et al., 2016; Ruedl et al., 2012; Smith et al., 1982; Smith et al., 1991; Soligard et al., 2015; Sugimoto et al., 2021). Few studies reported injury independently per discipline when multiple disciplines were included in the population (Andrew Naylor et al., 2023; Dubravcic-Simunjak et al., 2008; Dubravcic-Simunjak et al., 2003; Fortin et al., 2003; Smith et al., 1989). Furthermore, only one study reported injury in training (Campanelli et al., 2015) and only four studies reported injury in competition (Engebretsen et al., 2010; Ruedl et al., 2016; Ruedl et al., 2012; Soligard et al., 2015). The study reporting injuries during training had participants competing as single and pairs skaters. However, the results were not reported independently per discipline (Campanelli et al., 2015). The studies that reported injuries in competition only defined their

participants as figure skaters and did not specify the discipline in which they participated (Engebretsen et al., 2010; Ruedl et al., 2016; Soligard et al., 2015; Ruedl et al., 2012).

All 29 studies included reported injury. The injury prevalence ranged from 2.1%-34% (Campanelli et al., 2015; Ruedl et al., 2016). The only study reporting injury incidence per 1000 exposure hours and reported an incidence of 1.72 per 1000 hours of ice training (Kjaer et al., 1992). Figure skating had a slightly higher injury incidence when compared to other artistic sports, such as ballet (Smith, Gerrie, Varner, McCulloch, Lintner, Harris, 2015). This study was published in 1990 and had a follow up period of 1 year, indicating that data collection started before 1990 when the rules changed. The rule change placed more focus on jumps in a program. Thus, it would be reasonable to assume that there is a higher load and a greater incidence of injury due to the forces involved with jumps.

The main aim of this study was to identify, critically appraise, and summarize the current evidence on the epidemiology of injury and the associated injury risk factors in figure skating. After identifying and summarising the available literature the main findings of the systematic review was; the most frequently injured anatomical region was the lower limb, particularly the knee, foot and ankle. These results are similar to an earlier review completed on the epidemiology of figure skating injuries which reported the foot and the knee as most frequently reported anatomical sites on medical history forms (Han, Geminiani, Micheli, 2018). The most frequently reported pathology type was fractures and sprains. Importantly, even though less frequently reported, concussions were another pathology type noted based on potential serious implications of the injury. The identified and summarized literature further highlighted statistically significant intrinsic injury risk factors included older age, previous history of a stress fracture, and a higher body mass, and statistically significant extrinsic injury risk factors included training more than 12 sessions per week, skipping meals, hamstring and quadriceps immobility, training rather than competing, increased time on-ice and an increased boot-foot length difference. There are currently no other reviews which summarise the risk factors for injurie in figure skating to compare to. This review however provides readers with the first summary of risk factors in figure skating.

### 4.1 Clinical recommendations

The results from this review can assist clinicians in designing injury risk management strategies for figure skating.

4.1.1. We recommend that clinicians consider the context and the discipline of the individual figure skater during the design and implementation of these risk management strategies.

4.1.2. Clinicians should consider the lower limb, particularly the knee, foot and ankle, when designing injury risk management strategies as these are the most frequently reported injured body areas in figure skating.

4.1.3. Clinicians should be aware that fractures and sprains were the most frequently reported pathology types and consider this when designing injury risk management strategies.

4.1.4. Clinicians should consider certain training characteristics such as increased on-ice time and training more than 12 sessions a week as creating an increased risk for injury when designing risk management strategies.

## 4.2 Research recommendations

4.2.1. Future studies should define injury according to IOC consensus and use recognised frameworks to allow homogeneity across studies.

4.2.2. More studies to report injury per discipline or focusing only on one discipline are needed.

4.2.3. More epidemiological studies around male figure skaters are required.

4.2.4. More studies on epidemiology of injury and injury risk factors which follows prospective study design and using validated outcome measures are needed to improve the quality of research.

4.2.5. Separate studies focusing purely on injuries occurring in competition or in training are needed.

## 4.3 Limitations

Eight electronic databases were used for the search, and the references of all included studies were screened. One study deemed relevant, based on the title and abstract, could not be retrieved through the University of Pretoria's Library services or through multiple attempts to contact the author. In this systematic review, we limited our search to studies published in English. This strategy may have omitted relevant articles published in different languages. Since 1990, figure skating has become more demanding, with compulsory figures removed, increasing demand for more difficult jumps. This change in the technical demand of figure skating could have exposed figure skaters to different injuries and contributes to injury risk. As mentioned, eight included studies were conducted before or in 1990. Five of the included studies (Andrew Naylor et al., 2023; Dubravcic-Simunjak et al., 2008; Oleson et al., 2002; Pećina et al., 1990; Burt et al., 2022b) only focused on reporting injuries related to stress fractures and/or acute fractures. This may have contributed to bone reported as the most injured tissue type and fractures as the most commonly injured pathology type.

Objective 1.5.2 outlined in Chapter 1 was not completed. This objective was not completed as once more research was done on risk of bias, quality of evidence and level of evidence it was determined that level of evidence works on the assumption that the study design and risk of bias are directly linked (Sargeant, Brennan and O'Connor, 2022). Level of evidence focuses on the type of study design rather than context of the study as well as the methodological rigour of the study. The mythological rigour of the study is more important than the study design itself as a well conducted observational study could

have a lower risk of bias than a poorly conducted randomised control trial which would not be reflected in the level of evidence (Sargeant et al., 2022). The decision was then made to focus on risk of bias rather than level of evidence to better inform readers. In objective 1.5.4 in chapter one it was further determined that we would highlight injuries in two main categories, training vs competition injuries and gradual vs sudden onset injuries. We were able to categorize injuries in training or competition however we decided not to classify injuries into the category of sudden vs gradual onset. This decision was made as after more research it was determined that the International Olympic Committee (IOC) consensus statement no longer recommends that mode of onset be classified as gradual but rather focus on whether the mechanism of injury was acute or repetitive or a mixture of both (Bahr et al., 2020).

## 4.1. What is already known?

Figure skating is a physically demanding sport where skaters are exposed to a high injury risk.

## 4.2. What this review adds

- The knee, the ankle and the foot are the most commonly reported injured body areas.
- The most common pathology types reported are fractures, joint sprains, and bone stress injuries.
- The review identified three significant injury risk factors and eight significant extrinsic risk factors.
- There is a lack of literature specifically on the epidemiology of injury and injury risk factors for male figure skaters.

## 4.3. Conclusion

There is a lack of good quality literature investigating the epidemiology of figure skating injuries and injury risk factors. Most of the literature on figure skating injuries and injury risk factors follows a cross-sectional study design. Most of the available literature focuses on career prevalence of injury and does not look specifically at training or competition related injuries. The prevalence range of injury in figure skating is 2.1-34%. The most frequently injured anatomical region in figure skating is the lower limb, specifically the knee, foot and ankle. Our systematic review identified three significant intrinsic and eight significant extrinsic risk factors. Overall, there is a large variation in injury definition. Many studies used unvalidated outcome measures and did not follow a recognised framework when reporting injuries, creating substantial heterogeneity across the studies. Advances in figure skating injury and injury risk factor research will aid in developing and implementing injury prevention strategies allowing safer participation and longevity in the sport.

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## Appendix A: Proof of submission to Journal of athletic training

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

**Schmidt, Natasha <natasha.schmidt@semli.co.za>**

### JAT0311-23 Receipt of New Paper by Journal of Athletic Training

1 message

**Journal of Athletic Training** <jat@msubmit.net> 13 June 2023 at 00:38
Reply-To: jessica.ingle@health.slu.edu
To: natasha.schmidt@semli.co.za
Cc: carel.viljoen@up.ac.za

June 12, 2023

Dear Ms. Schmidt:

Thank you for the submission of your manuscript, "Epidemiology and associated injury risk factors in figure skating: a systematic review." It has been assigned number JAT0311-23.

The manuscript will now enter the review process. We will be in touch with you at the conclusion of the review process. You may check the status of your manuscript during that time by clicking on the link represented by the manuscript tracking number and abbreviated title and then clicking on "Check Status."

If you have any questions during the review process, please contact me at jat@slu.edu.

Sincerely,

Jessica Ingle
Staff
Journal of Athletic Training

# Appendix B: Search Strategy (Online supplementary appendix 1)

| ` | | Ovid MEDLINE | Results | PubMed | Results | Scopus | Results | SPORTDiscus | Results | CINAHL | Results | Health Source Nursing / Academic | Results | Cochrane Library | Results | MEDLINE EBSCO | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Set 1** | 1 | "pair skat*" | | "pair skat*" | | "pair skat*" | | "pair skat*" | | "pair skat*" | | "pair skat*" | | "pair skat*" | | "pair skat*" | |
| | 2 | "single skat*" | | "single skat*" | | "singles skat*" | | "single skat*" | | "single skat*" | | "single skat*" | | "single skat*" | | "single skat*" | |
| | 3 | "ice danc*" | | "ice danc*" | | "ice danc*" | | "ice danc*" | | "ice danc*" | | "ice danc*" | | "ice danc*" | | "ice danc*" | |
| | 4 | "synchronized skat*" | | "synchronized skat*" | | "synchronized skat*" | | "synchronized skat*" | | "synchronized skat*" | | "synchronized skat*" | | "synchronized skat*" | | "synchronized skat*" | |
| | 5 | "synchronised skat*" | | "synchronised skat*" | | "synchronised skat*" | | "synchronised skat*" | | "synchronised skat*" | | "synchronised skat*" | | "synchronised skat*" | | "synchronised skat*" | |
| | 6 | "figure skat*" | | "figure skat*" | | "figure skat*" | | "figure skat*" | | "figure skat*" | | "figure skat*" | | "figure skat*" | | "figure skat*" | |
| | 7 | "ice skat*" | | "ice skat*" | | "ice skat*" | | "ice skat*" | | "ice skat*" | | "ice skat*" | | "ice skat*" | | "ice skat*" | |
| Set 1 combined with **OR** operator | | | | | | | | | | | | | | | | | |
| **Set 2** | 14 | injur* | | injur* | | injur* | | injur* | | injur* | | injur* | | injur* | | injur* | |
| | 15 | epidemiolog* | | epidemiolog* | | epidemiolog* | | epidemiolog* | | epidemiolog* | | epidemiolog* | | epidemiolog* | | epidemiolog* | |
| | 16 | prevalence* | | prevalence* | | prevalence* | | prevalence* | | prevalence* | | prevalence* | | prevalence* | | prevalence* | |
| | 17 | incidence* | | incidence* | | incidence* | | incidence* | | incidence* | | incidence* | | incidence* | | incidence* | |
| | 18 | health* | | health* | | health* | | health* | | health* | | health* | | health* | | health* | |
| | 19 | 'medical encounter*" | | "medical encounter*" | | "medical encounter*" | | "medical encounter*" | | "medical encounter*" | | "medical encounter*" | | "medical encounter*" | | "medical encounter*" | |
| | 20 | "risk factor*" | | "risk factor*" | | "risk factor*" | | "risk factor*" | | "risk factor*" | | "risk factor*" | | "risk factor*" | | "risk factor*" | |
| | 21 | "protective factor*" | | "protective factor*" | | "protective factor*" | | "protective factor*" | | "protective factor*" | | "protective factor*" | | "protective factor*" | | "protective factor*" | |
| | 22 | "medical problem*" | | "medical problem*" | | "medical problem*" | | "medical problem*" | | "medical problem*" | | "medical problem*" | | "medical problem*" | | "medical problem*" | |
| Set 2 combined with **OR** operator | | | | | | | | | | | | | | | | | |
| Set 1 and Set 2 combined wuth **AND** operator | | | | | | | | | | | | | | | | | |
| Limiters applied as stipulated in the eligibility criteria. Not all databases have the option to apply all stipulated limiters. | | | | | | | | | | | | | | | | | |

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| FINAL RESULTS | |
| DUPLICATES REMOVED | |

| FINAL RESULTS | DUPLICATES REMOVED |
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# Appendix C: Data extraction sheet (Online supplementary appendix 2)

**Table 1: Methods and demographics**

| Authors and publication year | Study design | Data collection procedure (how did they collect data? Self-reported questionnaire, medical encounters etc.) | Setting (Country, competition or training, competition name, competition type, etc.) | Number of participants (n) | Age (mean, intervals etc – depending on how the authors reported the data) | Sex Frequency (n, % - as authors reported the data) | BMI (exactly as authors reported the data) |
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**Table 2: Epidemiology of injury**

| | | | Frequency (n, %) of injury characteristics as stated by 2020 IOC consensus statement | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| rs and publicatior | Injury definition | Follow-up period and intervals | Injury: Anatomical region | Injury: Body area | Injury: Tissue type | Injury: Pathology type | Injury severity (exactly as study reported the data) days lost, OSTRC severity score etc. | Incidence of injury (per 1000 hours, per 1000 figure skaters) | Injury Injury: prevalence |
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**Table 3: Associated injury risk factors**

| Authors and publ | Statistical analysis used to describe the association | Risk factors & association (For example: Number of figure skating sessions, OR 95% CI) | Protective factor & association (For example: Time spent figure skating OR 95% CI) |
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**Appendix D: Epidemiology of injury per study (Online supplementary appendix 3).**

| Author(s) and publication year | Injury definition | Follow-up period and intervals | Incidence of injury | Injury prevalence | Frequency (n, %) of injury characteristics as stated by 2020 IOC consensus statement | | | | Injury severity |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Anatomical region | Body Area | Tissue type | Pathology type | |
| Studies Referred to Career Occurrence of injuries (not particularly training or competition based) | | | | | | | | | |
| Naylor and Naylor (2021)(Andrew Naylor et al., 2023) | Not reported | Not Reported | Not Reported | Career Prevalence of stress fractures 24.4%, Single 23.7%, Pair 26.3%, Ice dance 24.0% | Upper Limb, Trunk, Lower Limb | Foot, Ankle, Lower Leg, Knee, Thigh, Hip/Groin, Back, Chest, Shoulder, Arm, Wrist, Hand | Bone | Singles Stress Fracture: Toe 2(5.7%), Foot 4 (11.4%), Ankle 8 (22.9%), Tibia/Shin 6 (17.1%), Fibula 1(2.9%), Knee 3(8.6%), Femur/Hips 2(5.7%), Wrist 1(2.9%), Arm 1 (2.9%), Coccyx (5.7%), Os Pubis 1(2.9%), Back 4 (11.4%). Pair Stress Fracture: Tibia/ Shin 5(83.3%), Wrist 1(16.7%) Ice Dance Stress Fracture: Fracture Foot 3(37.5%) Ankle (25%), Tibia/ Shin 1(12.5%), Wrist 1(12.5%), Back 1(12.5%) Stress Fracture Full Cohort: Toe 2(4.1%), Foot 7(14.2%), Ankle 10 (20.4%), Tibia / Shin 12(24.5%), Fibula (2%), Knee 3(6.1%), Femur/ Hips 2(4.1%), Wrist 3(5.9%), Arm 1(2%) Coccyx 2(4.1%), Os Pubis 1(2.0%), Back 5(10.2%) Acute Fracture (Full Cohort): Toe 2(4.1%) Foot 3(6.1%), Ankle 11(22.4%), Tibia/ Shin 3(6.1%), Fibula 1(2.0%), Knee 3(6.1%), Finger 4(8.2%), Hand 1(2%) Wrist 13(26.5%), Arm 5(10.2%), Coccyx 1(2%), Ribs 1(2%), Scapula 1(2%) | Not Reported |

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|---|---|---|---|---|---|---|---|---|---|
| Blewitt and Chockalingam (2011)(Blewitt, 2011) | Major Injury: kept participants off ice more than 21 days<br>Moderate: Injury kept them out of participation for between 8 – 21 days<br>Minor injuries: affected participants for 1 – 7 days | Not Reported | Not Reported | Not Reported | Upper Limb, Trunk, Lower Limb, Head And Neck | Knee 18%, Back 12%, Lower Leg 12%, Hip 11%, Ankle 9%, Wrist 9%, Foot 6%, Head/Face 6%, Thigh 5%, Neck 4%, Shoulder 3%, Arm 3%, Chest=1%, Other=1% | Muscle/Tendon 25.0%, Ligament 11.0%, Superficial Nervous Cartilage/Synovium/ Bursa Cartilage Injury Bone | Bruising 24%, Fracture 22%, Concussion 8%, Compartment Syndrome + Cuts+ Disc Thinning +Meniscus Tear 10% | Major Injury 50% Moderate Injury 19% Minor Injury 23% |
| Brown and mckeag (1987)(Brown et al., 1987) | Injuries severe enough to cause participants to miss one or more days of training | Not Reported | Not Reported | Not Reported | Pair: Axial Region 44%, Upper Extremity & Shoulder, 22%, Lower Extremity, Groin & Hips 33%<br>Singles**:** Axial 23%, Upper Extremity & Shoulders 11%, Lower Extremity Groin And Hips 67% | Pair: Head 33%, Chest 11%, Shoulders 11%, Wrist 11%, Hip 22%<br>Shin 11%,<br>Singles: Head 8%, Upper Back 5%, Lower Back 10%, Upper Arm 8%, Elbow 3%, Hip 13% Knee 44%, Leg 5% Groin 5%, Foot 8%, Ankle 8% | Single: Tendon3%, Nerve 3.0%<br>All: Superficial/Skin, Muscle/Tendon, Bone, Ligament/ Joint Capsule | Pair: Cut 11%, Hematoma 22%, Dislocation 11%, Concussion 33%, Fracture 22%<br>Single: Muscle Pull 31%, Sprain 8%, Fracture 21%<br>Cramps 8%, Concussion 8%, Hematoma 15%, Cut 5% | Average number for days missed: 10.3 successive days for each injury |
| Davis and Litman (1979)(Davis et al., 1979) | Not reported | Not reported | Not reported | Not reported | Lower Limb | Ankle, Foot | Ligament/ Joint Capsule, Superficial Tissue/ Skin, Bone Stress Injury, Muscle/ Tendon | Ankle Sprain 8 (18%), Osgood Schlatters 9 (20%)<br>Stress Fracture Of Greater Toe 1, Hammer Toe (69%), Bilateral Hallux Valgus 3, Dorsal Bunion Deformity 1, Corn | Not reported |
| Dubravcic-Simunjak *et al* (2008)(Dubravcic-Simunjak | No definition given however some of the stress fracture were confirmed on CT / MRI | Not reported | Not reported | Stress Fracture Females 16.7% Stress Fracture Males (13.8%) | Lower Extremity, Trunk | Lower Leg, Foot, Lower Back | Bone | Junior Females Single: Transverse Process L5 Stress Fracture 1(4.2%), Navicular Bone Stress Fracture 2(8.3%), Metatarsal Stress Fracture 4(16.7%), Fibula 2(8.3%), Tibia N 9(37.5%)<br>Junior Female Pairs: Tibia Stress | All 41 females and 25 males skaters with stress fracture returned to training free of symptoms to |

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| et al., 2008) | | | | | | | | Fracture 4(16.6%),<br>Fibula Stress Fracture 1 (4.2%)<br>Junior Female Ice Dance: Tibia Stress Fracture 1 (4.2%)<br>Junior Male Singles: Transverse Process L5 Stress Fracture 1(6.7%), Navicular Bone 1 (6.7%), Metatarsal 2 (13.3%), Tibia 6(40%), Fibula 2(13.3%)<br>Junior Male Pairs:<br>Metatarsal Stress Fracture 1 (6.65%), Tibia Stress Fracture 1 (6.65%)<br>Junior Male Ice Dance:<br>Tibia 1(6.7%)<br>Senior Female Singles:<br>Navicular Stress Fracture 2(11.8%), Metatarsal Stress Fracture 3(17.6%), Tibia Stress Fracture 6 35.3%), Fibula Stress Fracture 1(5.9%)<br>Senior Females Pairs:<br>Tibia Stress Fracture 3(17.6%), Fibula Stress Fracture 1(5.9%)<br>Senior Females Ice Dance:<br>Tibia Stress Fracture 1(5.9%)<br>Senior Male Singles:<br>Transverse Process L5 Stress Fracture 1(10%), Metatarsal Stress Fracture 2(20%), Tibia Stress Fracture 4(40%), Fibula Stress Fracture 1(10%)<br>Senior Male Pair:<br>Tibia Stress Fracture 1(10%), Senior Male Ice Dance:<br>Tibia Stress Fracture 1(10%) | pre injury skating level 2-8months after diagnosis. |
| Dubravcic-Simunjak *et al* (2006)(Dubravcic-Simunjak et al., 2006) | No definition given | Not reported | Incidence Of Acute Injuries Less Than 4 Years Ago In Females: Head (16.8%), | Not Reported | Acute Female Injuries: Head 79(19.8%), Trunk 28(7.1%), Upper Extremity | Acute Female Injuries:<br>Head 79, Neck 5, Thoracic Spine 2, Lumbar Spine 20, Abdominal Part 1, Upper Arm 8, Lower Arm 24, Shoulder 19, | Acute Female Injuries:<br>Knee Ligament/Meniscus 20<br>Acute Male Injuries:<br>Knee Ligament Or Meniscus 2, | Acute Female Injuries:<br>Head Contusion 23, Head Concussion 20, Head Laceration 23, Head Other 13, Neck Contusion 3, Neck Other 2, Thoracic Spine Contusion 2, Lumbar Spine Contusion 16, Lumbar Spine Other 4,<br>Abdominal Laceration 1, Upper Arm Contusion 8, Lower Arm Fracture 5, | Time Training was interrupted varied between 0 days to 6months depending on type of injury and severity |

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| | | | Trunk (4.3%) Upper Extremity (20.85), Lower Extremity (21.85%), Incidence Of Acute Injuries Less Than 4 Years Ago In Males: Head (14.3%), Upper Extremity (21.4%), Lower Extremity (35.7%), Incidence Of Acute Injuries More Than 4 Years Ago In Females: Head (3%), Trunk (2.8%), Upper Extremity (12.3%), Lower Extremity (18.1%) Incidence Of Acute | | 132(33.2%), Lower Extremity 159(39.9%) Acute Male Injuries: Head 2(14.3%), Upper Extremity 4(28.6%), Lower Extremity 8(57.1%) | Elbow 18, Wrist 29, Finger 34, Upper Leg 10, Lower Leg 21, Hip 20, Knee 66, Ankle 33, Foot 9, Acute Male Injuries: Head 2, Shoulder 1, Wrist 1, Finger 2, Lower Leg 2, Hip 1, Knee 3,Ankle 2 | Nervous, Superficial Tissue/Skin, Bone, Muscle / Tendon | Lower Arm Contusion 4, Lower Arm Hematoma 3, Lower Arm Laceration 12, Shoulder Contusion 8, Shoulder Hematoma 7, Shoulder Sprain/ Strain 4, Elbow Fracture 3, Elbow Contusion 4, Elbow Hematoma 3, Elbow Laceration 5, Elbow Sprain / Strain 3, Wrist Fracture 6, Wrist Contusion 5, Wrist Hematoma 3, Wrist Laceration 4, Wrist Sprain/Strain 11, Figure Fracture 6, Finger Contusion 6, Finger Hematoma 2, Finger Laceration 11, Finger Sprain /Strain 9, Upper Leg Contusion 5, Upper Leg Laceration 5, Lower Leg Fracture 8, Lower Leg Hematoma 2, Lower Leg Laceration 11, Hip Contusion 11, Hip Hematoma 5, Hip Laceration 4, Knee Fracture 1, Knee Contusion 19, Knee Hematoma 12, Knee Laceration 10, Knee Sprain Or Strain 4, Ankle Contusion 2, Ankle Sprain Or Strain 31, Foot Fracture 4, Foot Contusion 3, Foot Sprain Or Strain 2<br>Male Acute Injuries**:** Head Contusion 1, Head Concussion 1, Shoulder Contusion 1, Wrist Fracture 1, Finger Laceration 2, Lower Leg Laceration 2, Hip Contusion 1, Knee Laceration 1, Ankle Sprain / Strain 2<br>Overuse Female Injuries During Synchronized Skating Career**:** Groin Pain 10, Hamstring Syndrome 6, Jumpers Knee 4, Shin Splints 12, Achilles Tendinitis 7, Plantar Fasciitis 7, Ankle Impingement 7<br>Overuse Female Injuries During Figure Skating Career: Groin Pain 10, Hamstring Syndrome 4, Jumpers Knee 26, Osgood Schlatter 15, Shin Splints 13, Achilles Tendinitis 8, Plantar Fasciitis 7, | |

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| | | | Injuries More Than 4 Years Ago In Males: Upper Extremity (7.2%), Lower Extremity (21.4%) | | | | | Ankle Impingement 3, Stress Fracture 16<br>Overuse Male Injuries During Synchronized Skating Career**:**<br>Shin Splints 1<br>Overuse Male Injuries During Figure Skating Career:<br>Jumpers Knee 2, Os Good Schlatters 2 | |
| Dubravcic-Simunjak *et al* (2003) (Dubravcic-Simunjak et al., 2003) | Acute injuries are injuries occurring during a certain, determined, and limited time period that cause tissue damage.<br>Overuse injuries are injuries which occurred due to micro traumatic tissue damage in which the original cause of the injury cannot be proven and in most cases the skater neither feels nor remembers the time of the initial tissue damage | Not Reported | Female Overuse Injuries**:** Jumper's Knee (14.9%), Stress Fracture (19.8%), Shin Splints (13.9%), Groin Pain (7.9%), Ankle Impingemen(2.9%), Achilles Tendinitis (3.9%), Osgood Schlatter (8.9%), Plantar Fasciitis (2%), Hamstring Syndrome (4.9%) | | Upper Extremity Lower Extremity Head & Neck | Head, Shoulder, Arm, Wrist, Hand, Lumbosacral, Groin, Leg, Knee, Lower Leg, Ankle, Foot | Muscle / Tendon Bone Skin Ligament Superficial Tissue Nervous | Singles Female Acute Injuries**:** Ankle Sprain 10(16.8%), Knee Ligament Sprain 3(5.1%), Fracture Of Arm 2(3.4%), Fracture Of Leg 3(5.1%)<br>Female Pairs Acute Injuries**:** Ankle Sprain 8(13.5%), Knee Ligament Sprain 1(1.8%), Shoulder Dislocation 2(3.4%), Laceration In Leg 8(13.5%), Head Injury 8(13.5%), Arm Fracture 4(6.8%), Leg Fracture 2(3.4%), Knee Injury 2(3.4%)<br>Female Ice Dance Acute Injuries**:** Ankle Sprain 2(3.4%), Leg Laceration 4(6.8%), Male Single Acute Injuries: Ankle Sprain 10(15.4%), Knee Ligament Sprain 3(4.6%), Arm Fracture 4(6.2%), Leg Fracture 4(6.2%), Knee Injury 3(4.6%), Male Pair Acute Injuries: Ankle Sprain 7(10.8%), Knee Ligament Sprain 2(3.1%), Shoulder Dislocation 3(4.6%), Leg Laceration 5(7.7%), Head Injury 5(7.7%), Arm Fracture 2(3.1%), Leg Fracture 2(3.1%), Knee Injury 1(1.5%), Wrist Fracture 3(4.6%), Finger Fracture 1(1.5%) Male Ice Dance Acute Injuries**:** Ankle Sprain 2(3.1%), Knee Ligament Sprain 1(1.5%), Leg | Recovery Time Acute injuries Female skaters**:** 2weeks-2months, Recovery Time acute injuries male skaters**:** 5 Days-4 months, Recovery time overuse injuries female skaters**:** 6 weeks -5 months Recovery Time overuse injuries male skaters**:** 5weeks - 18months |

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| | | | Pairs Females Overuse Injuries: Jumper's Knee (3.9%), Stress Fractures (5.9%),Shin Splints (3.9%), Groin Pain (2%), Osgood Schlatter (2.9%) Ice Dancing Female Overuse Injuries: Groin Pain (1%), Achilles Tendinitis (1%), Singles Males Overuse Injuries: Jumper's Knee (16.1%), Stress Fracture (13.2%), Shin Splints (7.5%), Groin Pain (9.4%), Ankle | | | | | Laceration 4(6.2%), Head Injury 1(1.5%), Wrist Fracture 2(3.1%), Single Female Overuse Injuries: Navicular Bone Stress Fracture 3, Metatarsal Bones Stress Fracture 8, Tibia Stress Fracture 7, Fibula Stress Fracture Jumper's Knee 15(14.9%), Stress Fracture 20 (19.8%), Shin Splints 14(13.9%), Groin Pain 8(7.9%), Ankle Impingement 3(2.9%), Achilles Tendinitis 4(3.9%), Osgood Schlatter 9(8.9%), Plantar Fasciitis 2(2%), Hamstring Syndrome 5(4.9%) Pairs Females Overuse Injuries:<br>Jumper's Knee N=4 (3.9%)<br>Stress Fractures N=6 (5.9%)<br>Navicular Bone Stress Injury 1, Metatarsal Bone Stress Injury 2, Tibia Bone Stress Injury 2, Fibula Bone Stress Injury 1, Shin Splints 4(3.9%), Groin Pain 2(2%), Osgood Schlatter 3(2.9%) Ice Dancing Female Overuse Injuries: Groin Pain 1(1%), Achilles Tendinitis 1(1%) Singles Males Overuse Injuries: Jumper's Knee 17(16.1%), Stress Fracture 14(13.2%), Shin Splints 8(7.5%), Groin Pain 10(9.4%),<br>Ankle Impingement 5(4.7%), Achilles Tendinitis 5(4.7%), Osgood Schlatters 15(14.2%), Plantar Fasciitis 4(3.8%), Hamstring Syndrome 3(2.8%)<br>L4 Transverse Process Bine Stress Injury 1, Navicular 2, Metatarsal Bones 4, Tibia 5,<br>Fibula 2, Male Pairs Overuse Injuries: Jumpers Knee 2 (1.9%), Stress Fracture 4(3.8%), Shin Splints 4(3.8%), Groin Pain 3(2.7%), Osgood Schlatter 4(3.8%), Hamstring Syndrome 2(1.9%), | |

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| | | | Impingement (4.7%), Achilles Tendinitis (4.7%), Osgood Schlatters (14.2%), Plantar Fasciitis (3.8%), Hamstring Syndrome (2.8%) Male Pairs Overuse Injuries: Jumpers Knee (1.9%), Stress Fracture (3.8%), Shin Splints (3.8%), Groin Pain (2.7%), Osgood Schlatter (3.8%), Hamstring Syndrome (1.9%), Ice Dancing Overuse Injuries**:** Shin Splints | | | | | Ice Dancing Overuse Injuries**:** Shin Splints 2(1.9%), Groin Pain 4(3.8%), Metatarsal Bones Stress Injury 2, Tibia Bine Stress Injury 2 | |

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| | | | (1.9%), Groin Pain (3.8%) | | | | | | |
| King *et al* (2017)(King et al., 2017) | Acute injuries were defined as a sudden onset of pain that may occur from a traumatic event, Overuse injuries were defined as injuries developing gradually without a clear cause or traumatic event | NA | Not Reported | Not Reported | Head& Neck, Lower Extremity, Upper Extremity, Trunk | Not Qualified: Ankle 18%, Knee 12%, Foot 10%, Qualified: Ankle 20%, Knee 18%, Foot 11%, Back 11%, National/ International Skaters: Knee 18%, Foot 13%, Ankle 13%, Back 13%, Face 13%, All Other Body Parts Less Than 10% For All Subgroups | Superficial Tissue/Skin, Ligament/ Joint Capsule, Cartilage/ Synovium/ Bursa Cartilage Injury, Bone, Nervous, Muscle/ Tendon | Not Qualified (NQ)**:** Sprain 8(16.7%), Strain 8(16.7%), Fracture 3(6.3%), Stress Fracture 3(6.3%), Concussion 1(2.1%), Qualified (Q): Sprain 12(22.6%), Strain 7(13.2%), Fracture 8(15.1%), Stress Fracture 3(5.7%), Concussion 4 (7.6%), National Or International**:** Sprain 10(19.6%), Strain 6(11.8%), Fracture 5(9.8%), Stress Fracture 4(7.8%), Concussion 6(11.7%), Not Qualified Specific Injuries**:** Ankle Sprains 63%, Knee Sprain, Knee Contusion, Lower Back Injuries<br>Stress Fracture Of Lower Back, Qualified Specific Injuries**:** Ankle Sprains 73%, Knee Sprain<br>Knee Contusion, Knee Tendonitis, Osgood-Schlatter's Disease, Lower Back Injuries, Stress Fracture Of Lower Back,<br>National And International Specific Injuries**:** Ankle Sprains 43%, Knee Sprain, Knee Tendonitis, Osgood-Schlatters Disease, Lower Back Injuries<br>Stress Fracture Of Lower Back, Frequency Of Most Common Injuries Across All Groups**:** Ankle Sprains 11%, Concussion 7%, Knee Sprains 5%, Foot Fractures/ Stress Fractures 5% | Not Reported |
| Okamura *et al* (2014)(Okamura et al., 2014) | Not Reported | Not reported | Not Reported | Not Reported | Lower Extremity, Trunk | Knee, Ankle, Lumbosacral, Thigh | Bone, Ligament/Joint Capsule, Muscle/Tendon | Fracture 6.1%, Ligament Injuries 12.1%, Enthesitis 3%<br>Periostitis 3%, Lower Back Pain 9.1%, Spondylolysis 6.1% | Not Reported |

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| Pecina *et al* (1990)(Pećina et al., 1990) | Not reported | Average follow-up, 23 months , follow-up range 9 to 72 months | Not Reported | Not Reported | Lower Limb | Lower Leg, Foot | Bone | Fibula Stress Fracture, Tibia Stress Fracture, Ii Metatarsal Stress Fracture, Iv Metatarsal Stress Fracture, Base Of V Metatarsal Stress Fracture, Tarsal Navicular Stress Fracture | Not Reported |
| Simunjak *et al* (2020) (Simunjak et al., 2020) | Not reported | Not reported | Not Reported | Not Reported | Trunk, Upper Extremity, Lower Extremity , Head & Neck | Back Spine Issue Of Junior Skaters: Lumber Spine 64.2%, Thoracic 2.7%, Cervical 10.1%, Spine Issue Of Senior Skaters: Lumbar Spine Condition 55.7%, Cervical 2.7%,Thoracic 30.2%, Junior Skaters: Knee (28.2%), Forearm (29.1%), Wrist (20.4%), Shoulder (19.4%) Seniors Skaters: Ankle (22.0%), Wrist (24%), Shoulder (20.8%) | Bone, Muscle/Tendon , Nervous, Ligament | Junior Skaters**:** Scoliosis 14(3.6%), Cervical, Cervicocranial & Cervicobranchial Syndrome 6 (1.6%), Lumbosacral Syndrome & Lumboischialgia (13.5%), Disc Herniation 9(2.3%), Spondylolysis 3(0.8%), Spondylolisthesis 2(0.5%), No Specific Spinal Diagnosis 282(71.8%), Head Contusion (60.7%), Head Concussion (26.8%), Lower Extremity Sprain/ Strain (35.9%), Lower Extremity Contusion (24.6%), Lower Extremity Laceration (14.4%), Lower Extremity Fractures (5.1%), Upper Extremity Sprain (25.3%), Upper Extremity Fractures (20.4% ), Senior Skaters: Scoliosis 17(5.4%), Cervical, Cervicocranial & Cervicobranchial Syndrome 12(3.8%), Lumbosacral Syndrome & Lumboischialgia 54(17.2%), Disc Herniation (2.2%), Spondylolysis 3(1.0%), No Specific Spinal Diagnosis 186(59.0%), Head Contusion (31.5%), Head Concussion (46.8%), Lower Extremity Sprain Or Strain (38.4%), Lower Extremity Contusion (15.1%), Lower Extremity Fractures (6.3%), Upper Extremity Sprain (28.1%), Upper Extremity Fractures (21.9%) | 52.3% Senior skaters reported that spinal problems interfered with skating, 43.9% Junior skaters reported that spinal problems interfered with their skating |
| Smith and Micheli | Acute injuries were injuries which occurred at an identifiable moment | Not Reported | 0.09 serious injuries | Not Reported | Lower Limb, Upper Limb, | Head, Shoulder, Hand, Chest, Lumbosacral, | Bone, Ligament/Muscle, Nervous, | Male Acute Injuries**:** Peroneal Avulsion 1, Concussion 2, Patella Fracture 1, Finger Sprain 1, Groin | serious injuries: 8 |

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| (1982)(Smith et al., 1982) | Overuse injuries developed over longer period of time, probably as a results of repetitive micro trauma Serious injuries disabled the skaters from all practice for more than 72hrs | | per seriously skated year per skater, 0.12 per competitive year per skater, All acute injuries 0.18 serious injuries per seriously skated year per skater and 0.22 per competitive year per skater, overuse injuries 0.61 serious injuries per seriously skated year per skater and 0.78 per competitive year per skater | | Trunk, Head & Neck | Hip/Groin Thigh Knee Lower Leg Ankle Foot | Cartilage/ Synovium/ Bursa Cartilage, Ligament/ Joint Capsule, Superficial Tissue/Skin, | Muscle Strain 1, Ankle Sprain 1, Male Overuse Injuries: Lower Back Pain 1, Patellofemoral Knee Pain 2, Ankle Spurs 1, Medial Malleolar Swelling 1, Painful Coccyx 1, Peroneal Tendinitis 2, Probable Saphenous Phlebitis 1, Chronic Acromioclavicular Pain 1, Plantar Pain 1, Skin Infection Of Ankle 1, Female Acute Injuries: Torn Knee Ligament 1, Concussion 1, Fifth Metatarsal Fracture 1, Thumb Sprain 1, Groin Muscle Strain 1, Ischial Tuberosity Avulsion 1, Hamstring Strain 1, Laceration Of Chin 1, Rib Bruise 1, Female Overuse Injuries: Low Back Pain 5, Patellofemoral Knee Pain 2, Ankle Spurs 2, Malleolar Swelling 4, First Metatarsal Stress Fracture 1, Peroneal Tendinitis 1, Medial Shin Pain 3, Lateral Shin Splints 2, Painful Prominent Navicular Bones 2, Probable Trochanteric Bursitis 1, Ischial Hematoma 1 | |
| Studies that referred to injuries that occurred over a 1-year period (not particularly training or competition based) | | | | | | | | | |
| Ferrara and Hollings | Serious Injury caused participant to miss seven or more consecutive days of | Not Reported | 56% reported having at | Not Reported | Upper Extremity, Head / Neck, | Acute Serious Skating Injuries: Knee 6, Hip 6, Hand | Skin Cartilage Injury | Bruise Hip Or Knee, Arthritis Type Hip, Knee, Or Ankle Pain, Chronic Back Injury | Not Reported |

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| worth (2007)(Ferrara et al., 2007) | skating or related activity Less serious injury caused participants to miss less than seven consecutive days of skating or related activity | | least 1 injury in prev year 76% of these injuries were related to skating. | | Lower Extremity, Trunk | And Wrist 4, Head 1, Trunk/Back 5, Foot/Ankle 5, Shoulder 1, Chronic Serious Skating Injuries: Knee 2, Hip 3, Trunk And Back 7, Foot/Ankle 4, Shoulder 1, Acute Less Serious Skating Injuries: Knee 6, Hip 7,Hand /Wrist 2, Head 3, Trunk/Back 4, Foot/Ankle 1, Chronic Less Serious Skating Injuries: Knee 2, Hip 1, Trunk/Back 1, Foot/Ankle 4, Shoulder 1, | | | |
| Jederström *et al* (2021)(Jederström et al., 2021) | Severe sports injury episode was any injury or pain that had occurred in connection with training or competition in figure skating which resulted in >21 days of lost or altered participation in figure skating | Not reported | Not Reported | 1-year prevalence of a severe sports injury episode (31%), Point prevalence ongoing sports injury episode (19%) | Lower Extremity | Most Common Severe Injury Locations According To The Osiics Categories: Knee 25%, Ankle 20%, Hip/Groin 15%, Most Common Locations Of Current Injury According To The Osiics: Knee 24%, Ankle 24%, Foot 24% | Not Reported | Not Reported | Not Reported |
| Kjaer and Larsson (1990)(Kjaer et al., 1992) | To be considered as an acute or chronic injury the injury had to lead to time being lost from practice or competition | Weekly and at the end of the year | 1.37 per 1000h of total training 1.72 per 1000h of | Not Reported | Lower Extremity Injuries 83%, Upper Extremity, Trunk | Hand, Trunk Foot, Ankle Knee, Lower Leg | Muscle/Tendon, Nervous, Ligament / Joint Capsule | Ankle Sprain 6, Knee Sprain 2, Jumper's Knee 2, Shin Splints 2, Hand Ganglion 1, Achilles Tendinitis 1, Lumbar Train 2, Patellofemoral Pain Syndrome 1, Plantar Fasciitis 1 | The mean number of days lost training or competition due to injury was 4 Range of days |

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| | | | ice training | | | | | | lost training or competition due to injury (1-12days) |
| Smith *et al* (1991) (Smith et al., 1991) | Not reported | No specific interval: Participants Examined at Single camp first exam April 1986 & April 1987, Single skaters were followed-up at camp Sept 1987 Pair examined first camp April 1987 Pair skaters were followed-up at camp in July 1987 & Oct 1987 | Not Reported | Not Reported | Lower Extremity | Knee | Tendon | Jumper's Knee 8, Os-Good Schlatters Disease 3, Isolated Patellofemoral Pain Syndrome 4, Patellofemoral Pain Associated With Other Disorders 3, | Not reported |
| Studies that referred to injuries that occurred over a 3-year period (not particularly training or competition based) | | | | | | | | | |
| Kujala *et al* (1996)(K | Lower back pain low-back has to pain interfere with school work or leisure | yearly for 3 years | Not Reported | Not Reported | Trunk | Lumbosacral, Thoracic | Bone | Lower Back Ring Apophysitis Injury 2 | Not reported |

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| ujala et al., 1996) | activities for at least 1 week period.<br>Low-back pain experienced was defined by timing, duration, and location (demonstrated on a drawing). | | | | | | | | |
| Studies that referred to injuries that occurred over a 15-year period (not particularly training or competition based) | | | | | | | | | |
| Kowalczyk *et al* (2021)(Kowalczyk et al., 2021) | Acute injuries were injuries where symptoms began after a traumatic event at a single identifiable point in time, overuse Injuries were injuries that had a gradual onset of symptoms with no associated traumatic event. Knee extensor mechanism injuries were all injuries to anterior structure excluding bone contusion, & includes; injury to patella femoral joint, quadriceps tendon, apophyses & remain adjacent soft tissue. Quadriceps injuries were classified under upper leg Posterior column bone stress injuries were bone stress injuries to par articularis (spondylolysis) and pedicles | Not Reported | Not Reported | Not Reported | Upper Extremity, Lower Extremity, Trunk | For All Figure Skaters**:** Foot/Ankle (29.3%), Knee (19%), Back (15.6%), Hip (11.7%), Shoulder (4.7%), Wrist/Hand (4.3% ) Female Figure Skaters**:** Foot/Ankle (29.6%), Knee (19.3%), Back (15.8%), Hip (11.3%), Shoulder (4.6%), Wrist/Hand (4.3%), Male Figure Skaters: Foot/ Ankle (25.4%), Hip (16.4%), Knee (14.9%), Back (13.4%), Pelvis (6.0%), Lower Leg (6.0%), Shoulder (6.0%), | Muscle/Tendon, Nervous, Ligament / Joint Capsule, Bone Cartilage/Synovium/Bursa Cartilage Injury, Superficial Skin/Tissue | Tendinopathy 82(32.4%), Peroneal Tendinopathy 20(7.9%), Tibialis Posterior Tendinopathy 18(7.1%), Achilles Tendinopathy 16(6.3%), Extensor Tendinopathy Ankle / Foot 15(5.9%), Flexor Halluces Longus Tendinopathy 10(4.0%), Peroneal Subluxation 3(1.2%), Ligament Injuries In Foot/Ankle Ankle Sprain 32(12.6%), Plantar Fasciitis 6(2.4%), Syndesmotic Injury 5(2.0%), Lisfranc Ligament Injury 3(1.2%), Acute Cuboid Subluxation 1(0.4%), Chronic Cuneiform & Cuboid Micro Instability 1(0.4%), Torn Plantar Plate 1(0.4%), Metatarsal Bones Tress Reaction & Fracture 10(4.0%), Navicular / Accessory Navicular Bone Stress Reaction 8(3.2%), Distal Fibula Bone Stress Reaction 4(1.6%), Sesamoid Bone Stress Reaction 4(1.6%), Distal Tibia Bone Stress Reaction 3(1.2%), Cuboid Stress Reaction 2(0.8%), Talus Stress Reaction 2(0.8%), Other Bursitis/ Adventitial Bursitis 15(5.9%), Foot Pain & Ankle Pain Nos 4(1.6%), Ingrown Toe Nail 2(0.8%), Ungula Hematoma 2(0.8%), Skin Wound 2(0.8%), Partial Laceration To Achilles Tendon 1(0.4%), Chronic Bone Injuries 19(7.5%), Hallux Valgus Deformity 7(2.8%), Hoagland's Deformity 5(2.0%), Ocd | Not reported |

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| | | | | | | | | Talus 4(1.6%), Freiberg's Infarction 2(0.8%), Metatarsalgia 1(0.4%), Acute Bone Injuries 16(6.3%), Metatarsal Fracture 7(2.8%), Salter-Harris Fracture Of Distal Fibula 4(1.6%), Bone Contusion 2(1.2%), Salter-Harris Fracture Of Distal Tibia 2(0.8%), Ankle Impingement 12(4.7%), Posterior Ankle Impingement 6(2.4%), Sinus Tarsi Syndrome 5(2.0%), Lateral Ankle Impingement 1(0.4%), Apophysitis 8(3.2%), Calcaneal Apophysitis /Saver's Disease 8(3.2%), Neuropathy 8(3.2%), Tarsal Tunnel Syndrome 4(1.6%), Nerve Entrapment 2(0.8%), Neuropathy Nos 2(0.8%),Extensor Mechanism Of Injury 115(70.1%), Patella Femoral Pain Syndrome 54(32.9%), Patella Tendinopathy 24(14.6%), Osgood-Schlatter Disease 16(9.8%), Plica Syndrome 6(3.7%), Inferior Patellar Pole Apophysitis 5(3.0%), Patellar Subluxation 5(3.0%), Patellar Dislocation 3(1.8%), Hoffa's Fat Pad Impingement 2(1.2%), Internal Derangement 20(12.2%), Medial Collateral Ligament Injury 11(6.7%), Meniscus Tear 3(1.8%), Anterior Cruciate Ligament Tear 2(1.2%), Lateral Collateral Ligament Injury 2(1.2%), Ocd Of The Medial Femoral Condyle 2(1.2%), Acute Bone Injuries 19(11.6%), Knee Contusion 17(10.4%), Tibial Plateau Fracture 1(0.6%), Tibial Tubercle Fracture 1(0.6%), Other 7(4.3%), Iliotibial Band Syndrome 3(1.8%), Pes Anserinus Tendinopathy 3(1.8%), Knee Pain Nos 1(0.6%), Bone Stress Reaction And Fracture 3(1.8%), Physeal Stress | |

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| | | | | | | | | Injury At The Distal Femur & Proximal Tibia 2(1.2%), Stress Injury At The Tibial Epiphysis 1(0.6%), Posterior Column Injuries Of The Spine 80(59.3%), Posterior Column Bone Stress Injuries 43(31.9%), Facet Joint Arthropathy 13(9.6%), Extension-Based Back Pain 10(7.4%), Spinous Process Apophysitis 9(6.7%), Spinous Process Impingement 4(3.0%), Thoracic Facet Syndrome 1(0.7%), Other 49(36.3%), Mechanical Low-Back Pain Nos 32 (23.7%), Muscle Strain 12(8.9%), Muscle Spasm 3(2.2%), Back Pain In Lumbosacral Transitional Vertebrae 1(0.7%), Atypical Scheuermann Disease 1(0.7%), Anterior And Middle Column Injuries 6(4.4%), Intervertebral Disc Injury 6(4.4%) | |
| Studies that referred to general participation in figure skating (not particularly training or competition based) | | | | | | | | | |
| Brock and Striowski (1986)(Brock et al., 1986) | Injury is significant if it kept the skaters off ice or impaired his or her performance' | Not reported | Not Reported | Not reported | Not Reported | Not Reported | Soft Tissue 5, Fracture 1, Joint 2, Tooth Fracture 1 | Tendinitis 10, Chondromalacia Patellae 2 , Foot Fracture 1 | Average Time until return to practice (days): 17.4 Average Time to Full recovery (weeks) 10.6 |
| Fortin and Roberts (2003) (Fortin et al., 2003) | A significant injury was defined as one which precluded training or impaired performance. | Not Reported | Single skating injury per participant (prior to competition): 1.32, Pairs skating injury per | Not Reported | Head & Neck, Trunk, Upper Extremity, Lower Extremity | Frequency Of Injuries Reported Prior To Competition Senior Men 28: Head 2, Neck 1, Shoulder 1, Knee 5, Leg 4, Ankle 10, Back 5, Frequency Of | Nervous, Superficial Tissue/Skin, Muscle /Tendon, Bone, Synovium/ Burs Cartilage Injury, Ligament / Joint Capsule | Prior To Competition: Concussion 6, Contusion And Laceration To Head 22, Senior Men 7: Ligament (Carpal, Tarsal/ Spine)2, Tendon Stress Strain Or Injury 3, Bursa Nerve 1, Junior Men 3: Muscle Strain / Spasm 1, Ligament (Carpal, Tarsal/ Spine) 1, Tendon Stress Strain Or Injury 1, Novice Men 3: Ligament (Carpal, Tarsal/ Spine) 1, Fracture 1, Stitches | Not Reported |

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| | | | participant (prior to competition): 1.83, Ice dancing injury per participant (prior to competition): 0.97, Single skating injury per participant (during competition):0.29, Pairs skating injury per participant (during competition): 0.32, Ice dancing skating injury per participant (during competition) 0.17 | | | Injuries Reported Prior To Competition Junior Men 21: Head 1, Shoulder 1, Knee 6, Leg 2, Ankle 8, Back 3, Frequency Of Injuries Reported Prior To Competition Novice Men 15: Head 1, Neck 1, Knee 5, Leg 1, Ankle 2, Foot 1, Back 4, Frequency Of Injuries Reported Prior To Competition Senior Ladies 38: Head 2, Neck 1, Hip 4, Knee 6, Leg 8, Ankle 10, Back 7, Frequency Of Injuries Reported Prior To Competition Junior Ladies 7: Leg 2, Ankle 3, Back 2, Frequency Of Injuries Reported Prior To Competition Novice Ladies 10: Shoulder 3, Leg 1, Ankle 5, Back 1, Frequency Of Injuries Reported Prior To Competition Senior Pairs Men 34: Head 4, Neck 2, | | (Spikes / Falls) 1, Senior Ladies 7: Muscle Strain / Spasm 1, Tendon Stress Strain Or Injury 4, Bursa Nerve 1, Contusion 1, Junior Ladies 1: Muscle Strain / Spasm 1, Novice Ladies 3: Ligament (Carpal, Tarsal/ Spine) 1, Tendon Stress Strain Or Injury 1, Contusion 1, Senior Pairs Men 5: Ligament (Carpal, Tarsal/ Spine) 1, Tendon Stress Strain Or Injury 2, Contusion 1, Stitches (Spikes / Falls) 1, Senior Pairs Ladies 10: Ligament (Carpal, Tarsal/ Spine) 2, Tendon Stress Strain Or Injury 3, Meniscus 1, Contusion 1, Fracture 1, Stitches (Spikes / Falls) 2, Junior Pairs Men 3: Ligament (Carpal, Tarsal/ Spine) 2, Tendon Stress Strain Or Injury 1, Junior Pairs Ladies 1: Tendon Stress Strain Or Injury 1, Senior Dance Men 1: Stitches (Spikes / Falls) 1, Senior Dance Ladies 5: Muscle Strain / Spasm 2, Meniscus 1, Contusion 1, Stitches (Spikes / Falls) 1, Junior Dance Men 1: Ligament (Acrpal, Tarsal/ Spine) 1, Junior Dance Ladies 3: Muscle Strain / Spasm 1, Tendon Stress Strain Or Injury 1, Contusion 1 | |

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| | | | | | | Shoulder 7, Hip 3, Knee 3, Leg 2, Ankle 7, Foot 2, Back 4, Frequency Of Injuries Reported Prior To Competition Senior Pairs Ladies 30: Head 4, Shoulder 1, Hip 3, Knee 6, Leg 4, Ankle 8, Back 4, Frequency Of Injuries Reported Prior To Competition Junior Pairs Men 18: Head 2, Shoulder 2, Hip 1, Knee 2, Leg 1,Ankle 5, Foot 1, Back 4,Frequency Of Injuries Reported Prior To Competition Junior Pairs Ladies 28: Head 4, Shoulder 1, Hip 2, Knee 6, Leg 4, Ankle 8, Back 3, Frequency Of Injuries Reported Prior To Competition Senior Ice Dance Men 13: Head 3, Hip 2, Knee 3, Leg 1, Ankle 2, Back 2, Frequency Of Injuries Reported Prior To Competition | | | |

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| | | | | | | Senior Ice Dance Ladies 18: Head 2, Neck 1, Shoulder 2, Hip 1, Knee 3, Leg 1, Ankle 5, Back 3, Frequency Of Injuries Reported Prior To Competition Junior Ice Dance Men 13, Shoulder 1, Hip 2, Knee 3, Leg 1, Ankle 5, Back 1, Frequency Of Injuries Reported Prior To Competition Junior Ice Dance Ladies 12:Head 3, Hip 1, Knee 5, Leg 1, Ankle 1, Back 1, Frequency Of Injuries Reported During The Competition Senior Men 7: Hip 2, Leg 2, Back 3, Frequency Of Injuries Reported During The Competition Junior Men 3: Knee 1, Wrist 2, Frequency Of Injuries Reported During The Competition Novice Men 5: Hip 1, Knee 1, Foot 2, Back 1, Ribs, Frequency Of Injuries Reported | | | |

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| | | | | | | During The Competition Senior Ladies 7: Hip 1, Knee 2, Leg 3, Ankle 1, | | | |
| Oleson *et al* (2002)(Oleson et al., 2002) | No Reported | Not Reported | Not Reported | Not Reported | Upper Limb, Lower Limb, Trunk | Lumbar Spine, Wrist, Metatarsal, Tibia, Talus | Bone | Stress Fracture | Not reported |
| Smith and Ludington (1989)(Smith et al., 1989) | Serious Injury were injuries causing skaters to miss 7 or more consecutive days of normal training, Less serious and short term injuries were injuries which markedly limited the skater's training program for fewer than 7 days & long term injuries were present for 4 weeks but limited the skaters training to a minor degree | Not reported | Not reported | Not reported | Serious Injury Pairs Skaters: Head & Neck, Trunk, Upper Extremity, Lower Extremity Serious Injury Ice Dance Injuries: Trunk, Lower Extremity, Less Serious Injuries Pair Skaters: Upper Extremity, Trunk, Less Serious Injuries Ice Dancer Upper Extremity, Lower Extremity | Serious Injury: Head 2, Shoulder & Trunk 3, Hand & Wrist 3, Hip And Thigh 6, Knee 7, Foot And Ankle 12, Less Serious Injuries**:** Shoulder & Trunk 5, Hand & Wrist 1, Hip And Thigh 2, Knee 4, Foot And Ankle 4, | Muscle/ Tendon, Nervous, Bone, Cartilage/Synovium/Bursa Cartilage Injury, Ligament/ Joint Capsule, Superficial Tissue/Skin | Serious Acute Injuries: Facial Laceration With Concussion, Lumbar Strain 2, Wrist Sprain, Finger Fracture, Groin Muscle Strain 4, Thigh Contusion 2, Biceps Fem Strain, Patellar Fracture, Patellar Contusion, Lateral Meniscus Tear 2, Calf Laceration, Ankle Sprain, Foot Sprain, Foot Contusion, Serious Overuse Injuries: Lumbar Sprain 1, Hand Lumbrical Strain, Pes Anserine Bursitis, Peroneal Tendinitis 2, Anterior Tibial Tendinitis, Achilles Tendinitis, Malleolar Bursitis 2, Excoriated Plantar Wart, Plantar Fasciitis, Acute Less Serious Injuries: Costochondral Contusion, Lumbar Strain, Finger Laceration, Buttock Laceration, Rectus Femoris Strain, Shin Laceration, Toe Fracture, Serious Overuse Injuries, Rhomboid Strain 2, Rotator Cuff Strain, Patellofemoral Pain Syndrome 3, Patellar Tendinitis, Malleolar Bursitis, Metatarsal Periostitis | Not Reported |
| Sugimoto *et al* (2021)(S | Not Reported | Not Reported | Not Reported | Not Reported | Trunk | Lumbosacral | Not Reported | Lower Back Injury Specialized Skater 21(25.6%), Lower Back Injuries Non-Specialized Skaters 12(24.0%) | Not reported |

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| ugimoto et al., 2021) | | | | | | | | | |
| Training related studies | | | | | | | | | |
| Campanelli *et al* (2015)(Campanelli et al., 2015) | Retrocalcaneal Bursitis<br>Clinical Findings (CF): Painful soft tissue swelling. Medial & Lat to Achilles tendon at the level of posterosuperior calcaneus<br>Ultra sound finding (US): Anechoic area in the subtendinous area just above the calcaneus<br>Superficial calcaneal bursitis<br>CF: Visible, painful, solid swelling area with discoloration of skin; most often located at the posterolateral calcaneus; in chronic bursitis, pain was only felt after the b bursa was exposed to friction<br>US: Hypoechoic or anechoic area between the skin and the Achilles tendon; in case of chronic bursitis, a hyperechoic area can be seen between the skin and the Achilles tendon<br>Skin Callus<br>CF: Incompressible swollen area with ipercheratosis at the level of the Achilles insertion or its middle third with no associated redness unless just exposed to friction (shoe)<br>US: Hyperechoic area in the | None | Not Reported | Point prevalence: Retrocalcaneal Bursitis (34%), Posterior Heel Skin Calluses (29%), Superficial Calcaneal Bursitis (28%), Hard Toe Corns (25%), Lateral Ankle skin Abrasion (21%), Achilles middle third skin callus / bursitis (16%), Skin irritation on navicular bone medial prominence (13%), Anterior ankle skin abrasion (12%), Other (Achilles paratendinopathy, patellar tendon Tendinopathies, Patellar femoral pain syndrome, anterior talofibular lig | Lower Extremity | Foot, Ankle, Knee | Muscle/Tendon, Bone, Cartilage/Synovium/Bursa Cartilage Injury, Superficial Skin/Tissue | Retrocalcaneal Bursitis 26, Posterior Heel Skin Calluses 22, Superficial Calcaneal Bursitis 21, Hard Toe Corns 19 Lateral Ankle Skin Abrasion 16, Achilles Middle Third Skin Callus / Bursitis 12, Skin Irritation On Navicular Bone Medial Prominence 10, Anterior Ankle Skin Abrasion 9, Other (Achilles Paratendinopathy, Patellar Tendon Tendinopathies, Patellar Femoral Pain Syndrome, Anterior Talofibular Lig Conditions, So Good Schlatters Disease And Sever Disease N<9 | Not Reported |

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| | superficial subskin area with no<br>deeper anechoic area<br>Skin Abrasion tendinopathy<br>CF: Grazed area<br>Pain, swelling, and exercise-induced pain<br>US: NA<br>Achilles Paratendinopathies<br>CF: Pain in the area of the Achilles and swelling, tenderness,<br>and crepitus in the middle third of the Achilles<br>US: Hypoechoic layer is seen abutting posterior surface of<br>the distal Achilles tendon<br>Osgood-Schlatters disease<br>CF: Tenderness and swelling at insertion of patellar tendon at<br>Tibial tubercle in adolescents<br>US: Irregularity at the ossification nucleus of the Tibial<br>tubercle<br>**Sever Disease**<br>CF: Tenderness to palpation and in normal activity (eg, walking)<br>US: Irregularity at the ossification nucleus of the posterior<br>calcaneus<br>Skin irritation on navicular bone medial prominence<br>CF:Redness of the skin on the medial navicular and tenderness<br>to palpation on the evident navicular bone prominence, generally due to over | | | conditions, so good schlatters disease and sever disease (<10%) | | | | | |

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| | pronated flat foot<br>US: NA<br>Patellofemoral pain syndrome<br>CF: Anterior knee pain ‘‘behind’’ or around patella. Also,<br>possible findings of patellar maltracking<br>US:NA<br>Anterior talofibular ligament condition<br>CF:Tenderness to palpation on the lateral compartment of the<br>ankle caused by tear or strain of the anterior talofibular ligament caused by a previous ankle sprain<br>US: Hypoechoic area on the ligament in case of strain; anechoic area in case of tear of the anterior talofibular ligament | | | | | | | | |
| Competition Related studies | | | | | | | | | |
| Ruedl *et al* (2016)(Ruedl et al., 2016) | Participants were considered injured if: he/she received medical attention regardless of the consequences with respect to absence from competition or training | Duration of the competition | Not Reported | Total Figure skating injury Prevalence 2.1% | Trunk | Lumboscaral | Muscle /Tendon | Muscle Cramp Or Spasm 1(3.3%) | The one injury which occurred did not result in Time loss |
| Ruedl *et al* (2012)(Ruedl et al., 2012) | Participants were considered injured if: he/she received medical attention regardless of the consequences with respect to absence from competition or training | Duration of the competition | Not Reported | Not Reported | Not Reported For Figure Skating Specifically | Not Reported For Figure Skating Specifically | Not Reported For Figure Skating Specifically | Not Reported For Figure Skating Specifically | Number of figure skaters affected by time loss 2(25%) |

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| Soligard et al (2015)(Soligard et al., 2015) | Injury was defined as new or reoccurring musculoskeletal symptoms or concussion incurred in competition or training during Sochi Olympic games receiving medical attention regardless of consequences with respect to absence from competition or training. | Follow-Up was Duration of the competition | Not Reported | Not Reported | Not reported specifically for figure skaters | Not reported specifically for figure skaters | Not reported specifically for figure skaters | Not reported specifically for figure skaters | Severe injuries were injuries at caused estimated absence from training or competition of more than 1 week. Injuries in figure skating that lead to greater than or equal to 1 day time loss 2(1.3%), Injuries in figure skating that lead to greater than 7 days' time loss 1 (10.7%) |

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|---|---|---|---|---|---|---|---|---|---|
| Engebretsen *et al* (2010)(Engebretsen et al., 2010) | An athlete was defined as injured if they received medical attention regardless of the consequences with respect to absence from competition or training. | Not Reported | Incidence proportions (%) per 1000 athletes: Female figure skating injuries(1%), Male figure skating injuries(12%) | Not Reported | Head & Neck, Trunk Upper Extremity, Lower Extremity | Not Reported Specifically For Figure Skating | Not Reported Specifically For Figure Skating | Not Reported Specifically For Figure Skating | Figure skating: no injuries lead to time loss. |

## Appendix E: Letter of statistical support

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Denkleiers • Leading Minds • Dikgopolo tša Dihlalefi

DEPARTMENT OF STATISTICS

### LETTER OF STATISTICAL SUPPORT

Date: 21st May 2022

This letter is to confirm that ***Natasha Therese Schmidt***, studying at the University of Pretoria, discussed the project with the title "***The epidemiology of injury and associated risk factors amongst figure skaters: a systematic review.***" with me.

The aim of the study is to identify, critically appraise, and summarize the current evidence on the epidemiology of injury and the associated injury risk factors in figure skaters.

I hereby confirm that I am aware of the project and undertake to assist with the statistical analysis of the data generated from the project, if sufficient data are available for a meta-analysis.

Tanita Botha
Department of Statistics
Internal Statistical Consultation Service
Tanita.Botha@up.ac.za

## Appendix F: University of Pretoria ethical approval

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

**Institution:** The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 18 March 2022 and Expires 18 March 2027.
- IORG #: IORG0001762 OMB No. 0990-0279 Approved for use through June 30, 2025 and Expires 07/28/2026.

Faculty of Health Sciences **Research Ethics Committee**

17 August 2023

**Approval Certificate**
**Annual Renewal**

Dear Ms NT Schmidt,

**Ethics Reference No.: 302/2022 – Line 1**
**Title: The epidemiology of injury and associated risk factors amongst figure skater: A systematic review**

The **Annual Renewal** as supported by documents received between 2023-07-11 and 2023-08-16 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2023-08-16 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Renewal of ethics approval is valid for 1 year, subsequent annual renewal will become due on 2024-08-17.
- Please remember to use your protocol number (302/2022) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

**Ethics approval is subject to the following:**

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

**Yours sincerely**

**On behalf of the FHS REC, Professor C Kotzé**
MBChB, DMH, MMed(Psych), FCPsych, Phd
***Acting Chairperson**: Faculty of Health Sciences Research Ethics Committee*

*The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)*

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Lefapha la Disaense tša Maphelo