# WE KNOW A LOT ABOUT LITTLE AND LITTLE ABOUT A LOT: A CONTEXTUALIZED SCOPING REVIEW ON INJURY PREVENTION IN ALPINE SKI RACING

**JOURNAL: Scandinavian Journal of Medicine & Science in Sports**

**Authors**

Oriol Bonell Monsonís[1], Jörg Spörri[2,3], Marit Warsen[1], Caroline Bolling[1,4], Vincent Gouttebarge[4,5,6], Evert Verhagen[1]

1. Amsterdam Collaboration on Health & Safety in Sports, Department of Public and Occupational Health, Amsterdam Movement Sciences, Amsterdam UMC, University Medical Centres – Vrije Universiteit Amsterdam, Amsterdam, the Netherlands
2. Sports Medical Research Group, Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Zurich, Switzerland.
3. University Centre for Prevention and Sports Medicine, Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Zurich, Switzerland.
4. Amsterdam Movement Sciences, Musculoskeletal Health & Sports, Amsterdam, The Netherlands
5. Amsterdam UMC location University of Amsterdam, Orthopaedic Surgery and Sports Medicine, Meibergdreef 9, Amsterdam, The Netherlands.
6. Section Sports Medicine, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa.

**Corresponding author**

Oriol Bonell Monsonís. E-mail address: o.bonellmonsonis@amsterdamumc.nl

**SUPPLEMENTARY INFORMATION**

**Table of Contents**

**Supplementary information 1: Search terms, strategies, and results**

SEARCH TERMS AND STRATEGIES

1. Population: Alpine skiing
2. Concept: Prevention and Injury
3. Context: Alpine ski racing (all levels)
4. Limits and exclusions

a) Search strategy for PubMed

Database: PubMed

Date searched: April 1, 2023

Limits:

- <1997 to Present;
- English, German, French and Spanish Language

Results: 395

Search Strategy for PubMed

| No | Searches |
|---|---|
| **1** | alpine |
| **2** | skiing OR ski |
| **3** | injury OR injuries |
| **4** | 1 AND 2 AND 3 |
| **5** | limit 4 to English, German, French and Spanish Languages |

b) Search strategy for SPORTDiscus

Database: SPORTDiscus (EBSCOhost Web)

Date searched: April 1, 2023

Limits:

- <1997 to Present;
- English, German, French and Spanish Language

Results: 419

Search Strategy for SPORTDiscus

| No | Searches |
|---|---|
| **1** | TX alpine |
| **2** | TX ski* |
| **3** | TX injur* |
| **4** | 1 AND 2 AND 3 |
| **5** | limit 4 to English, German, French and Spanish Languages |

c) Search strategy for Web of Science

Database: Web of Science

Date searched: April 1, 2023

Limits:

- <1997 to Present;
- English, German, French and Spanish Language

Results: 547

Search Strategy for Web of Science

| No | Searches |
|---|---|
| **1** | alpine (All Fields) |
| **2** | ski* (All Fields) |
| **3** | injur* (All Fields) |
| **4** | 1 AND 2 AND 3 |
| **5** | limit 4 to English, German, French and Spanish Languages |

d) Search strategy for EMBASE

Database: EMBASE

Date searched: April 1, 2023

Limits:

- <1997 to Present;
- English, German, French and Spanish Language

Results: 462

Search Strategy for EMBASE

| No | Searches |
|---|---|
| **1** | alpine |
| **2** | ski* |
| **3** | injur* |
| **4** | 1 AND 2 AND 3 |
| **5** | limit 4 to English, German, French and Spanish Languages |

**Supplementary information 2: Data extraction chart**

**Table 1** Data extraction of the included studies regarding their study feature, methodology, context, injury data, injury etiology, injury prevention strategy, and implementation data. *ACL: anterior cruciate ligament; ACL-R: anterior cruciate ligament reconstruction; AI: asymmetry index; AWG: Asian Winter Games; CC: control group; CMJ: countermovement jump; DBB: deadbug bridging exercise; DH: downhill; DJ: drop jump; DPSI: dynamic postural stability index; EC: European Cup; F: female/s; FIS: International Ski and Snowboarding Federation; GRF: ground reaction force; GS: giant slalom; IG: intervention group; IOC: International Olympic Committee; ISS: Injury Surveillance System; LSI: limb symmetry index; M: male/s; MRI: magnetic resonance imaging; NMT: neuromuscular training; OSTRC: Oslo Sports Trauma Research Centre; PT: patellar tendon; RR: risk ratio/s; RTS: return-to-sport; SBRS: ski boot rear stiffness; SG: Super-G; SL: slalom; SRC: Sports-related concussion; SSC: stretch-shorten-cycle; SSPT: Swiss Ski Power Test; TD: team doctor; US: ultrasound; WC: World Cup; WOG: Winter Olympic Games.*

| **Study features** | | **Sample characteristics** | **Study context** | **Injury data** | **Injury etiology** | **Injury prevention strategy** | **Implementation data** | |
|---|---|---|---|---|---|---|---|---|
| **Author, year, study design, country/federation** | **Aim of the study** | **a) Sample size (n)**<br>**b) Gender**<br>**c) Age** | **a) Competition level (alpine skiing discipline)**<br>**b) Time of the season/year** | **a) Injury definition**<br>**b) Injury reporting method** | **Injury mechanisms and/or inciting events** | **Description** | **a) Compliance/adherence definition**<br>**b) Compliance/adherence rate** | **c) Implementation context description** |
| Abrahamson J et al., 2020[40]<br>Prospective cohort study<br>Sweden | to investigate the correlation between the presence and the size of cam morphology, hip pain, and activity | a) n=60<br>b) F30, M30 (elite: F6, M10)<br>c) 23.6 ± 1.1 | a) Youth level<br>b) Winter season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | level at a minimum of 5 years follow-up, in a cohort of young elite skiers. | | | | | | | |
| Alhammoud M et al., 2022[41]<br>Pilot study<br>France | to examine the impact of repeated ski runs on electromyographic activity (EMG) of the knee extensors and flexors in elite alpine skiers, by characterizing on-field neuromuscular adjustments and EMG variability in elite skiers repeating four high-intensity runs. | a) n=19<br>b) F8, M11<br>c) F23 ± 2, M24 ± 5 | a) WC- and EC-levels (all disciplines)<br>b) Winter in southern hemisphere | | | | | |
| Alhammoud M et al., 2020[42]<br>Prospective cohort study<br>France | to investigate the joint kinematic characteristics of elite alpine skiers according to leg and discipline. | a) n=20 (WC n=13, EC n=7)<br>b) F9, M11<br>c) F23.0 ± 2.0; M24.0 ± 5.0 | a) WC-level and EC-level (all disciplines: SL/GS n=15; SG/DH n=5)<br>b) Two summer seasons (winter seasons in southern hemisphere: Argentina) | | | | | |
| Alhammoud M et al., 2019[43]<br>Experimental field study<br>France | to explore a novel isokinetic analysis approach | a) n=28<br>b) F14, M14 | a) WC-level and EC-level (all disciplines) | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | throughout the range of motion based on statistical parametric mapping; and to determine the influence of sex and discipline on torque and hamstrings-quadriceps ratio in elite alpine skiers. | c) F21.2 ± 3.0; M23.0 ± 3.8 | b) Preseason | | | | | |
| Alhammoud M et al., 2021[44]<br>Prospective cohort study<br>France | to characterise the thermoregulatory responses of elite alpine skiers during their activity. | a) n=4 (staff n=6)<br>b) M<br>c) 28 ± 6 | a) WC-level and Olympic medalists (GS and SL)<br>b) Winter season | | | | | |
| Alhammoud M et al., 2020[1]<br>Prospective cohort study<br>France | to prospectively investigate the rate and pattern of injuries over 5 years among competitive European Cup alpine skiers and to compare winter competitive season with the summer off-season. | a) n=133<br>b) F54, M79<br>c) 20.8 ± 2.7 | a) EC-level<br>b) Multiple seasons | a) Fuller CW et al., definitions[45,46]<br>b) Tailored questionnaire forms[1] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Anghileri M et al., 2014[47]<br>Experimental lab study | to demonstrate that numerical simulations can be used to support the design of safety net systems, reduce the number of tests to perform for the certification, and, hence, reduce time and cost associated to the development of high standard safety nets. | | | | | Design and development of high standard safety net systems | | |
| Bachmann C et al., 2008[48]<br>Cross-sectional study (descriptive)<br>Switzerland | to investigate the level-specific prevalence of upper extremity injuries. | a) n=87<br>b) F24, M63<br>c) F20.7 ± 3.9, M22.8 ± 4.8 | a) WC-, EC-, FIS competitions and youth levels<br>b) Multiple seasons | a) Fuller CW et al., definitions[45,46]<br>b) OSTRC questionnaire on health problems (and on-site interviews)[49,50] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Barth M et al., 2022[51]<br>Prospective cohort study<br>Austria | to describe the incidence per 1000 runs and sex-specific RR of in-competition severe injury events (SIEcomp) in elite alpine ski racing; to examine the change in the seasonal SIEcomp incidence per 1000 runs over 24 seasons; and to compare the SIEcomp incidence per 1000 runs and the respective sex-specific RR in downhill, super-G, giant slalom, and slalom. | a) n=2333 (WC n=963; EC n=732; Junior n=638)<br>b) F1042, M1291<br>c) Junior to adults | a) WC-level, EC-level and Junior (all disciplines)<br>b) Multiple seasons | a) Other and tailored definitions: severe injury[51]<br>b) Paper-and-pencil questionnaire ; Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | | | |
| Barth M et al., 2020[2]<br>Prospective cohort study<br>Austria | to describe the incidence and gender-specific risk ratio of acute on-snow severe injury events (SIE) in elite alpine ski racing; to examine the development of the severe injury events incidence over 22 seasons; and to analyse the SIE with respect to the severely injured body parts and body structures. | a) n=2225 (WC n=921; EC n=696; Junior n=608)<br>b) F994, M1231<br>c) Junior to adults | a) WC-level, EC-level, Junior (all disciplines)<br>b) Season: in- and off-season | a) IOC consensus statement definitions[52]<br>b) Paper-and-pencil questionnaire ; Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bere T et al., 2014[21]<br>Editorial | | | a) WC-level | | | Establishment of safety culture: FIS Injury Surveillance System (2006-07) | | |
| Bere T et al., 2011[14]<br>Case series | to describe the skiing situation leading to ACL injuries in the WC alpine skiing based on a technical analysis of the video recordings. | a) n=20 (n=14 experts) | a) WC-level (all disciplines): Current WC coaches (n=10), former WC coaches (n=3), current national team's coaches, and recently retired WC ski racer (n=1)<br>b) Winter season | | ACL: (1) "Slip-catch", (2) "dynamic snowplough", (3) "landing back-weighted". | | | |
| Bere T et al., 2011[22]<br>Case series | to describe the injury situations and mechanisms of ACL injuries among WC alpine skiers based on systematic analysis of video recordings. | a) n=20 (n=7 experts)<br>b) F7, M13 | a) WC-level (all disciplines). Skiing biomechanists (n=4), and orthopaedic surgeons (n=3)<br>b) Winter season | | ACL: (1) "Slip-catch", (2) "dynamic snowplough", (3) "landing back-weighted". | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bere T et al., 2014[10]<br>Case series | to describe the injury situations in WC alpine skiing based on systematic video analysis of real injury situations. | a) n=69<br>b) F24, M45 | a) WC-level<br>b) Winter season | | Turning or landing from a jump. | | | |
| Bere T et al., 2014[9]<br>Cross-sectional study<br>Austria, Canada, Finland, France, Germany, Italy, Norway, Sweden, Switzerland, Slovenia | to compare the risk of injury in female versus male World Cup (WC) alpine skiers, based on 6-year data from the FIS ISS. | a) n=1593<br>b) F708, M885 | a) WC-level (all disciplines)<br>b) Multiple winter seasons | a) Fuller CW et al., definitions[45,46]<br>b) FIS Injury Surveillance System (ISS) based on annual retrospective interviews[19] | | | | |
| Bere T et al., 2013[53]<br>Case series | to examine the detailed time course of knee and hip kinematics of 2 typical slip-catch situations in World Cup alpine skiing reported through the International Ski Federation (FIS) Injury Surveillance System. | a) n=2<br>b) F1, M1<br>c) 27.5 ± 1.5 | a) WC-level (SL)<br>b) Winter season | | "Slip-catch" | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bergeron MF et al., 2012[54]<br>Consensus | to highlight selected key environment-related risk factors that continue to challenge Olympic and other international-level athletes; and to re-emphasise and provide additional recommendations to address and minimise those risks associated with recent and ongoing incidents of environmentally prompted illness, injury and death in sport. | | | | | No competitions below -27C; Combination of air temperature and wind speed, plus the speed of the competitor. | | |
| Bergstrom KA et al., 2001[55]<br>Prospective cohort study<br>Norway | to report the amount of overuse injuries, malalignment, and indistinct knee pain in athletic adolescents aged 15–19 years at a ski high school. | a) n=14<br>b) F8, M6<br>c) Mean 17 (Range 15-19) | a) Youth level<br>b) 1 year | a) Other and tailored definitions: knee complaints[55] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bergstrom KA et al., 2004[56]<br>Prospective cohort study<br>Norway | to explore the relationships between different type of skiing and activity levels to overuse injuries, small abnormalities, and back pain alone in growing athletes from 15 through 19 years attending a Norwegian ski high school | a) n=14<br>b) F8, M6<br>c) Mean 17 (Range 15-19) | a) Youth level<br>b) 1 year | a) Other and tailored definitions: back complaints[56] | | | | |
| Bielmeier CM et al., 2021[57]<br>Cross-sectional study (descriptive)<br>United States of America | to establish detailed information about ski laceration injuries among adolescent and young adult US ski racers, on (a) the frequency, severity, and body location of laceration injuries during skiing and (b) the skiing environment and ski maintenance method used at the time of the laceration injury. | a) n=249<br>b) F50%, M50%<br>c) Range 10-24 | a) Junior and elite level (all disciplines)<br>b) Off-season | b) Retrospective survey[57] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bruhin B et al., 2020[58]<br>Pilot study<br>Switzerland | to identify differences in sections of the runs (course setting, steepness) and performance parameters (e.g., speed, time per turn, turn phases etc.) among young and older athletes. | a) n=57 (elite n=7; U21 n=11; U18 n=13; U16 n=6; U14 n=13; U12 n=7)<br>b) M<br>c) Elite >21 (born 1992±2.18) | a) Elite level, U21, U18, U16, U14, U12 (GS)<br>b) Multiple winter seasons | | | | | |
| Carraro A et al., 2020[59]<br>Cross-sectional study<br>Italy | to describe the demographics, sports exposure, and other sports- or warm-up-related practices of adolescent competitive alpine skiers; to assess the prevalence of lower back complaints in this specific cohort with respect to sex, category, and discipline preference; to explore their lower back complaints severity (i.e., intensity and disability); and to investigate the potential relations with training attributes. | a) n=188 (U16 n=128; U18 n=60)<br>b) F78, M110<br>c) F: 16.0 ± 1.0; M: 16.1 ± 1.1 | a) U16, U18<br>b) End of competitive season | a) Other and tailored definitions[59]<br>b) Tailored questionnaire forms[59] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Chang JY et al., 2021[60]<br>Case study | to provide an in-depth analysis of physiotherapy treatments to athletes during the Olympic Winter Games at the two polyclinics; and to have a better understating of the levels and the patterns of physiotherapy services in each polyclinic. | a) n=322<br>b) F42, M83 (of total n=125 visitors) | a) WOG<br>b) Winter season | b) Electronic report forms in the WOG events[52] | | | | Athletes who visited the physiotherapy services during the 2018 PyeongChang Olympic Winter Games. 17 sport physiotherapists and 2 team leaders from the Korean Physical Therapy Association. Main reasons accounted for injury rehabilitation (48.3%), recovery (44.8%), and injury prevention (6.9%). Causes of injury were: overuse (49.4%), previous injury (29.9%), fall (6.9%), contact with an object (6.9%), non-contact trauma (4.6%), and equipment (2.3%). Encounter rate per 1000 athletes: 180.1 (n= 322 alpine ski racers). Type of treatments provided: electrophysical modalities (34.7%), treatment exercise (21.5%), soft tissue technique (14%), joint manipulation/mobilisation (13.2%), strapping/taping (7.2%), cryotherapy (4.2%), verbal advice and guidance (2.6%), and general massage (2.3%). |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Crestani L et al., 2014[61]<br>Retrospective cohort study<br>France | to comprehend the ACL risk factors in the elite skiers between 2002 and 2010. | a) n=42<br>b) F24, M18<br>c) Range F: 16-28; M: 23-32 | a) Elite level and WOG event<br>b) Season: in- and off-season | b) Online questionnaire (French National team)[61] | | | | |
| Csapo R et al., 2018[62]<br>Retrospective cohort study | to analyse the fitness level of convalescent elite alpine skiers after completion of physical rehabilitation (5–6 months post-surgery) and the changes in competition performance after return to sports. | a) n=46<br>b) F26, M20<br>c) F: 20.0 ± 2.7; M: 21.6 ± 3.2 | a) WC-level, Continental Cup-level, FIS competitions level [CC: EC and Nor-Am Cup]<br>b) Rehab/RTS | b) Tailored questionnaire forms[62] | | | | |
| Csapo R et al., 2020[63]<br>Prospective cohort and pilot study<br>Austria | to investigate potential changes in the anterior cruciate ligament (ACL) structure of alpine ski racers over the course of an entire season using quantitative magnetic resonance imaging (T2 mapping). | a) n=4<br>b) M<br>c) Mean 22 | a) EC-level and WC-level (SL, GS)<br>b) Season: in- and off-season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Csapo R et al., 2021[64]<br>Retrospective cohort study | to analyse the effects of graft selection, sex, injury complexity and time to return to competition on the odds to suffer secondary ACL injury (either re-rupture or contralateral ACL tear) in professional alpine skiers. | a) n=30<br>b) F17, M13<br>c) 21.6 ± 4.0 | a) FIS competitions level, EC-level and WC-level | | | | | |
| Doyle-Baker PK et al., 2020[65]<br>Cross-sectional study (descriptive)<br>Canada | to describe the participation of all sport and physical activity by type and volume, and the secondary aim was to provide insight into the injuries reported and health indicators (health care utilization, illness, medication use) in adolescent youth ski club racers in Western Canada. | a) n=96<br>b) F52, M44<br>c) 11.5 ± 1.1 (range: 9.3-13.7) | a) Youth level | a) Other and tailored definitions: concussion[65]<br>b) Tailored questionnaire on concussions (Canada)[65] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Eberle R et al., 2017[66]<br>Experimental lab study | to analyse the effect of different SBRS on the maximal ACL tensile force during injury prone landing movements in alpine ski racing using the musculoskeletal simulation model of Heinrich et al. (2014) with an improved ski boot model. | | | | | | | |
| Eberle R et al., 2019[67]<br>Experimental laboratory study | to develop a planar multibody simulation model of a mono-skier and investigate transversal vibrations of unedged skis during schussing in the fall line over rough (random) ski slopes. | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ellenberger L et al., 2021[68]<br>Experimental field study<br>Switzerland | to evaluate the reliability of quantifying thigh muscle activation patterns and dynamic knee valgus at peak ground reaction force during DJ landings; to provide reference values for female and male youth competitive alpine skiers; and to study their associations with age, anthropometrics, biological maturation and the occurrence of knee overuse complaints. | a) n=144<br>b) F47, M67<br>c) F: 14.7 ± 0.6; M: 14.9 ± 0.5 | a) U16 | a) Other and tailored definitions: knee complaints[68]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | |
| Ellenberger L et al., 2020[69]<br>Cross-sectional and experimental field study<br>Switzerland | to introduce a novel biomechanical approach for quantifying athletes' rear chain stabilization performance during DBB and to assess its test-retest reliability; to describe DBB performance in two distinct populations (i.e., female and male competitive alpine skiers of the U16 | a) n=171 (U16 n=133; elite n=38)<br>b) U16: F49, M84; elite: F19, M19 | a) U16 and elite level | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | Youth athletes (U15 and U10) participating in a physical fitness competition at the final event of the "SwissPass Smile Challenge". Participants could access to a video tutorial before the event to practice and become familiarised with the exercise. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | category and competitive alpine skiers of the elite category) with respect to sex; and to investigate the association between DBB performance, age, anthropometrics, biological maturation, skiing performance and the occurrence of back overuse complaints in U16 skiers undergoing phases of rapid musculoskeletal growth. | | | | | | | |
| Ellenberger L et al., 2020)[70] Cross-sectional study Switzerland | to evaluate dynamic knee valgus of competitive alpine skiers during DJ landings and a SLS task with respect to sex and sportive level and to establish normative reference values; to investigate the relationship between dynamic knee valgus during DJ landings and biological maturation; to explore the differences | a) n=141 (Youth n=104, elite n=37) b) Youth: F44, M60; Elite: F19, M18 c) Youth U15: F13.7 ± 0.7; M13.9 ± 0.6; Elite= F21.7 ± 2.5; M23.0 ± 2.7 | a) U15 and elite level b) Prior competition season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | between an assessment of dynamic knee valgus during DJ landings and during SLS tasks; and to examine the test-retest reliability of dynamic knee valgus assessments during DJ landings and SLS tasks. | | | | | | | |
| Engebresten L et al., 2010[71]<br>Prospective cohort study | to describe the risk of injury and illnesses occurring during the XXI Winter Olympic Games in Vancouver 2010. | a) n=308<br>b) F133, M175 | a) WOG<br>b) Winter season | a) IOC consensus statement definitions[52]<br>b) IOC injury surveillance system for multisport events[52] | | | | |
| Fauve M et al., 2002[72]<br>Manual<br>Switzerland | | | | | | | | |
| Fitze DP et al., 2022[73]<br>Prospective cohort study<br>Switzerland | to provide reference values regarding lumbar multifidus morphology of female and male youth competitive alpine skiers; to investigate the influence of biological maturation on lumbar multifidus morphology; to verify whether | a) n=85 (U16 n=45, U15 n=40)<br>b) F28, M57<br>c) F14.7 ± 0.7, M14.9 ± 0.5 | a) U16, U15 (youth level)<br>b) One year | a) Other and tailored definitions: overuse-related back complaints[73]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49, 50] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | lumbar multifidus morphology is associated with DBB performance; and to compare the lumbar multifidus morphology of symptomatic and asymptomatic skiers and examine the potential clinical relevance of these findings. | | | | | | | |
| Fitze DP et al., 2022[74]<br>Prospective cohort study<br>Switzerland | to describe biceps femoris long head morphology in youth competitive alpine skiers with respect to sex, age and maturity offset; and to investigate its association with the occurrence of traumatic injuries of the lower extremities in the upcoming season. | a) n=95<br>b) F33, M62<br>c) F14.7 ± 0.6; M14.9 ± 0.7 | a) Youth level | a) Fuller CW et al., definitions[45,46]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | |
| Florenes TW et al., 2009[8]<br>Cross-sectional study<br>Austria, Canada, Finland, France, Germany, Italy, Norway, Sweden, Switzerland, Slovenia | to describe the risk of injury and the injury pattern among competitive World Cup alpine skiers during the competitive season. | a) n=521<br>b) F229, M292 | a) WC-level (all disciplines)<br>b) Multiple winter seasons | a) Fuller CW et al., definitions[45,46]<br>b) Retrospective interviews[8] | | | | |
| Florenes TW et al., 2011[19]<br>Methodological study | to compare three different methods to record injuries | a) n=141 | a) WC-level (all disciplines) | a) Fuller CW et al., | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Switzerland, Germany, France, Finland, Canada, Norway | among World Cup skiers and snowboarders, prospective reporting by the TD, prospective reporting by the medical staff of selected World Cup teams and retrospective interviews with World Cup athletes at the end of the World Cup season. | | b) Winter season | definitions[45,46]<br>b) Retrospective interviews; Prospective injury reports from the team doctor; Prospective injury reports (medical team registration)[19] | | | | |
| Florenes TW et al., 2012[75]<br>Cross-sectional study<br>Germany, Switzerland, Canada, Finland, France, Norway, Italy, Sweden, Austria | to describe the injury risk and injury pattern among World Cup athletes in alpine skiing, freestyle skiing, snowboarding, ski jumping, cross country skiing and Nordic combined based on data from the FIS ISS. | a) n=521 (alpine skiing)<br>b) F229, M292 | a) WC-level (all disciplines)<br>b) Winter season | a) Fuller CW et al., definitions[45,46]<br>b) Retrospective interviews[75] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Franchi MV et al., 2019[76]<br>Cross-sectional study<br>Switzerland | to provide novel descriptive data and reference values on MEHS in competitive alpine skiers, which could be of strategical interest for future novel injury prevention approaches starting from youth competitive level and age. | a) n=170 (U15 n=139; elite n=31)<br>b) Youth: F51, M88; elite: F19, M12<br>c) Youth: 13.8 ± 0.6; elite: 21.7 ± 2.8 | a) U15 and elite level<br>b) Youth: preseason; elite: off-season | | | | | |
| Fröhlich S et al., 2021[3]<br>Prospective cohort study<br>Switzerland | to estimate the injury risks for a national team cohort among female and male competitive alpine skiers during the off-season preparation and competition periods based on a prospective approach and an "any complaint" injury definition; and to describe the patterns of traumatic and overuse injuries with respect to injury severity, body location and injury type. | a) n=44<br>b) F25, M19<br>c) 21.4 ± 2.8 | a) WC-level, EC-level, FIS competitions level<br>b) Season: in- and off-season | a) Fuller CW et al., definitions[45,46]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | |
| Fröhlich S et al., 2020[77]<br>Prospective cohort study<br>Switzerland | to prospectively investigate the prevalence and severity of knee-related, back- | a) n=26 (SL-GS n=15; SG-DH n=11)<br>b) F | a) Elite athletes (all disciplines)<br>b) Off-season | a) OSTRC definitions[49,50]; Fuller CW et al., | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | related and hip-related overuse injuries in top female elite alpine skiers during the off-season preparation period; and to assess the relationship of knee complaints with traumatic preinjuries and the total training hours. | c) 20.91 ± 2.67 | | definitions[45,46] b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | |
| Fröhlich S et al., 2020[78] Cross-sectional study Switzerland | to describe the knee overuse-related clinical complaints and MRI abnormalities in a cohort of youth competitive alpine skiers around the growth spurt. | a) n=108 b) F 42, M66 c) 14.83 ± 0.58 | a) Youth level b) 1 year | a) Other and tailored definitions[78] b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | |
| Fröhlich S et al., 2020[79] Case report study | to describe a case of medial malleolar bursitis in a competitive alpine skier, which, to our knowledge, has not been previously reported. | a) n=1 b) M c) 23 | a) Competitive level | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gallo-Vallejo MA et al., 2017[80]<br>Prospective cohort study | to analyse and describe the injuries and diseases suffered during the 27th Winter Sports Universiade held in February 2015 in Granada and Sierra Nevada, Spain. | a) n=174 (Alpine skiing only)<br>b) F70, M104 | a) WSU (WOG event)<br>b) Winter season | a) IOC consensus statement definitions[52]<br>b) Tailored questionnaire forms[80] | | | | |
| Gilgien M et al., 2020[81]<br>Cross-sectional study | to assess how course-setting characteristics, entrance speed and terrain incline influence the mechanics of turning (i.e., turn speed, turn radius, and ground reaction force and impulse); and to determine whether manipulation of horizontal gate offset or vertical gate distance is a more reasonable way to reduce speed and risk of injury in real WC alpine GS races. | a) n=6 | a) Former WC or current EC racer (GS)<br>b) Multiple winter seasons | | | Speed reduction of 0.5 m/s by decreasing the vertical gate distance (20 to 29%) in GS, with less adverse side effects on safety than increasing the horizontal gate offset (33 to 55%) | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gilgien M et al., 2021[82]<br>Cross-sectional study | to assess whether course-setting characteristics, entrance speed and terrain incline influence speed through a turn; and to assess whether changes in course-setting aimed at reducing speed have negative consequences on turn radius, impulse and turn forces in Super-G. | a) n=4 | a) WC-level (Super-G)<br>b) Multiple winter seasons | | | Speed reduction of 0.5 m/s by decreasing the vertical gate distance (13%) in Super-G, with less adverse side effects on safety than increasing the horizontal gate offset (51%) | | |
| Gilgien M et al., 2015[83,84]<br>Cross-sectional study | to characterize course setting, terrain geomorphology and their relationship to speed in male WC giant slalom, super-G and downhill. | a) n=14<br>b) M | a) WC-level (GS, SG, DH)<br>b) Multiple winter seasons | | | | | |
| Gilgien M et al., 2018[85]<br>Cross-sectional study | to capture the external forces acting on forerunners skiing World Cup races in GS, SG and DH. | b) M<br>c) 25.1 ± 3.5 | a) Forerunners: former male WC-level or current EC-level (GS, SG and DH)<br>b) Winter season | | | Speed reduction by increasing ski-snow friction force in GS and SG, while increasing ski-snow friction force is as effective as increasing | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | air drag force in DH | | |
| Gilgien M et al., 2014[24] Case series | to quantify these important skiing-related variables for the disciplines GS, SG and DH. We also investigated whether these variables could explain the differences in the number of injuries per 1000 runs among the disciplines. | a) n=34 | a) Former WC or current EC racer (GS, SG, DH) b) Multiple winter seasons | | | | | |
| Gilgien M et al., 2016[86] Experimental lab study | to investigate the effect of modifications in ski geometry (ski length, ski width) and standing height of DH skis on speed and kinetic energy while skiing a WC DH course. | a) n=2 b) M c) 34.5 ± 4.5 | a) Retired WC athletes (DH) b) Winter season | | | Reducing kinetic energy by approximately 3% with longer skis with reduced standing height and reduced profile width in steep terrain as in DH | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gong T et al., 2022[87]<br>Experimental lab study | to develop an improved simulation method based on inverse dynamics and to assess the effects of improper skiing motions on ACL injuries. | | | | | | | |
| Götschi T et al., 2022[88]<br>Prospective case-control study<br>Switzerland | to examine the quantitative PT properties (morphological and mechanical) shear of the PT using quantitative B-mode US and 3D mapping of SWV in a large athletic cohort of youth competitive alpine skiers as a function of demographic factors; to identify distinct regional PT properties of skiers with distal and/or proximal PT complaints vs. skiers with healthy PTs; and to compare the sensitivity and specificity of this novel US SWE approach with the diagnostic accuracy of MRI as the gold standard approach | a) n=106<br>b) F40, M66<br>c) Range 13-15 | a) Youth level | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | to detect PT complaints. | | | | | | | |
| Götschi T et al., 2022[89]<br>Case-control study<br>Switzerland | to investigate differences in PT SWV in competitive alpine skiers compared to age-matched healthy control subjects; to evaluate sex-specific differences in PT SWV; and to describe potential differences in regional SWV patterns in both cohorts. | a) n=30<br>b) F14, M16<br>c) 23.6 ± 2.50 | a) Elite level<br>b) Off-season | b) OSTRC questionnaire on health problems[49,50] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Haaland B et al., 2016[12]<br>Time trend analysis (based on retrospectively acquired data) | to investigate the effect of the new ski regulations on the rate and pattern of injuries by comparing data before (2006–2012) and after (2012–2015) their implementation. | a) n=2402<br>b) F1058, M1344 | a) WC-level (all disciplines)<br>b) Multiple winter seasons | a) Fuller CW et al., definitions[45,46]<br>b) FIS Injury Surveillance System (ISS) based on annual retrospective interviews[19] | | Introduction of new equipment rules by FIS for the 2012–2013 season: longer skis with less-shaped skis (higher sidecut radius) and reduced profile width | | Data analysed during nine WC seasons (2006-2015) in the final event of each season. Athletes must have started in at least one WC or World Ski Championship (WSC) event throughout the season, and must be identified by the head coach as an official member of the WC team to be included. Injuries occurred during both races and official trainings to WC, WSC, WOG, FIS and other competitions or on-snow trainings were registered. |
| Han PD et al., 2022[90]<br>Prospective cohort study | to evaluate the characteristics and frequencies of injury and illnesses occurring among all athletes during the Beijing 2022 Olympic Winter Games. | a) n=2897 (all)<br>b) F1304, M1593 (all) | a) WOG event<br>b) Winter season | a) IOC consensus statement definitions[52]<br>b) Tailored form of interview and questionnaire[90] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hanimann J et al., 2023[91]<br>Cross-sectional study<br>Switzerland | to determine whether there are distinct differences in leg axis and core stability between soccer players and skiers; to investigate whether youth soccer players and alpine skiers exhibit leg axis and core stability differences between the dominant and nondominant sides; and to explore the outcomes of applying common sport-specific asymmetry thresholds to these two distinct cohorts. | a) n=61<br>c) 15.7 ± 0.1 | a) Youth level<br>b) Prior competition season | | | | | |
| Heinrich D et al., 2014[92]<br>Experimental lab study | to develop a musculoskeletal modeling and simulation approach to investigate the effect of a perturbed landing position, i.e., joint angles and trunk orientation, on peak ACL force during the subsequent | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | landing movement. | | | | | | | |
| Heinrich D et al., 2018[93] Experimental lab study | to quantify the effect of landing height on peak ACL force during jump landing in downhill skiing, and to compare the effects of landing height and landing position. The landing position was represented by the trunk lean of the skier. | | a) (DH) | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Heinrich D et al., 2022[94]<br>Experimental lab study | to develop a three-dimensional musculoskeletal model of an alpine skier capable of simulating turning manoeuvres; and to apply the musculoskeletal skier model in combination with a forward dynamics optimization framework to estimate dynamically consistent kinematics, ground reaction forces and joint moments during a turning manoeuvre. | | | | | | | |
| Hildebrandt C et al., 2017[95]<br>Case-control study<br>Austria | to compare trunk strength capacities and flexion/extension core ratios in elite alpine skiers with a matched control group according to gender. | a) n=109 (WC n=23, EC n=43, Junior n=44)<br>b) F56, M53<br>c) F: 22.4 ± 3.4; M: 22.1 ± 3.6 | a) WC-level, EC-level and Junior<br>b) Precompetitive season | | | | | |
| Hildebrandt C et al., 2019[96]<br>Prospective cohort study<br>Austria | to develop a user-friendly training-and-injury database as the basis for prospective and reliable data collection. | a) n=82<br>b) F31, M51<br>c) F: 11.8 ± 1.3; M: 11.6 ± 1.5 | a) Junior level<br>b) Multiple school years | b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hildebrandt C et al., 2021[97]<br>Prospective cohort study<br>Austria | to prospectively examine training load as it relates to the occurrence, severity, and burden of injuries and illnesses in youth alpine ski racers. | a) n=91<br>b) F39, M52<br>c) F: 12.0 ± 1.3; M: 12.1 ± 1.0 (range 10-14) | a) Youth level<br>b) Season: in- and off-season | a) Fuller CW et al., definitions[45,46]<br>b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | | | |
| Hildebrandt C et al., 2013[98]<br>Cross-sectional study<br>Austria | to investigate the profile of ski specific injuries over a two-year period in a cohort of youth alpine skiers from a special sport boarding school who compete in high-level sports. Of particular interest was the comparison of overuse and traumatic injuries during the winter and summer seasons. | a) n=104<br>b) F43, M61<br>c) Range 15-18 | a) Youth level<br>b) Multiple seasons | a) Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) Retrospective interviews[98] | | | | |
| Holden WM et al., 2022[99]<br>Case series | to describe a case series of these injuries in order to increase awareness and encourage further studies on injury mechanisms and prevention. | a) n=5<br>b) F2, M3<br>c) Median 16 (Range 15-20) | a) (SL, SG, GS)<br>b) Winter season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ineichen J et al., 2021[100]<br>Cross-sectional study (descriptive)<br>Switzerland *(n=86)*, United States of America and Austria *(n=75)* | to analyze the type and incidence of dental injuries among professional FIS-ranked skiers in relation to their alpine skiing discipline (speed vs. technical), performance level, and years of experience. | a) n=190 (WC n=5; EC n=40; FIS competitions n=113)<br>b) M | a) WC-level, EC-level, FIS-competitions level<br>b) Multiple seasons | | | | | |
| International Ski and Snowboarding Federation (FIS). 2016[101]<br>Manual | | | | | | | | |
| International Ski and Snowboarding Federation (FIS). 2021[102]<br>Manual | | | | | | | | |
| Javet M et al., 2022[103]<br>Cross-sectional study<br>Switzerland | to explore reasonable application purposes and potential confounders of the SSPT in youth competitive alpine skiers. | a) N=144 (U16 n=31, U15 n=81, U14 n=32)<br>b) F57, M87 (F: U16 n=9, U15 n=34, U14 n=14; M: U16 n=22, U15 n=47, U14 n=18)<br>c) 14.5 (14.3–14.6) | a) U16, U15, U14<br>b) Prior competition season | a) Fuller CW et al., definitions[45,46]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | |
| Jedvaj H et al., 2021[104]<br>Cross-sectional study (descriptive)<br>Croatia, Slovenia, Serbia and Montenegro | to examine the level of kinesiophobia in skiers who have sustained knee injuries. | a) n=33<br>b) F22, M11<br>c) 24 ± 7.4 | a) Competitive skiing for 14.7 ± 5.4 years (all disciplines) | a) Other and tailored definitions[104]<br>b) Retrospective survey[104] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | b) Winter season | | | | | |
| Jordan MJ et al., 2014[105]<br>Cross-sectional study<br>Canada | to quantify bilateral lower limb functional asymmetry using the CMJ and SJ phase-specific kinetic impulse asymmetry index (AI) in uninjured and ACL-R elite ski racers and asymmetry in lower limb muscle mass measured with dual X-ray absorptiometry (DXA) scanning. | a) n=18 (IG n=9; CG n=9)<br>b) F9, M9<br>c) 24.55 ± 2.39 | a) WC-level<br>b) Start off-season | | | | | |
| Jordan MJ et al., 2015[106]<br>Case-control study<br>Canada | to perform a comprehensive hamstrings and quadriceps muscle strength assessment and to evaluate lower limb muscle mass in a group of actively competing elite alpine ski racers with/without ACL-R. | a) n=21 (n=8)<br>b) F8, M13<br>c) 22.55 ± 2.8 | a) WC-level<br>b) Start off-season | | | | | |
| Jordan MJ et al., 2016[107]<br>Cross-sectional study<br>Canada | to assess the effects of acute neuromuscular fatigue on vertical jump performance, bilateral functional | a) n=22<br>b) F10, M12<br>c) F: 23.6 ± 1.8; M: 26.5 ± 5.8 | a) WC-level<br>b) Prior competition season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | asymmetry, and quadriceps/hamstring muscle activity in elite alpine ski racers with/without ACLR. | | | | | | | |
| Jordan MJ et al., 2017[108]<br>Case series<br>Canada | to evaluate the concurrent pathologies, including meniscal tears, chondral lesions, and multiligament injuries, at the time of primary ACLR in elite alpine ski racers; to evaluate the future state of the chondral lesions and meniscal tears; and to evaluate the occurrence of ACL reinjury in elite alpine ski racers by reviewing postoperative reports obtained from surgeries that occurred subsequent to the primary ACLR. | a) n=32<br>b) F17, M15 | a) Elite level<br>b) Season: in- and off-season | b) Tailored questionnaire forms[108] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Jordan MJ et al., 2022[109]<br>Case-control study<br>Canada | to evaluate by a nonlinear analysis the time-course change in SSC capacity in non-injured female alpine ski racers between 16 and 32 years of age; to evaluate the recovery of SSC function after ACL injury and ACLR that included recovery of the eccentric deceleration and concentric kinetic impulse, respectively, as manifested by temporal change in absolute SSC function and the between-limb kinetic impulse AI. | a) n=32<br>b) F<br>c) Range 16-32 | a) Elite level | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Kashluba KA (2018)[110]<br>Quasi-experimental study<br>Canada | to investigate if a neuromuscular training (NMT) warm-up program during preseason conditioning in Southern Alberta ski-clubs would improve lower limb balance and maximal muscular power when compared to a standard preseason program in alpine ski-racers 10-13 years old (U14). | a) n=84<br>b) F45, M39<br>c) F11.4 (10.9, 11.8 99% CI), M10.9 (10.5, 11.4 99% CI) | a) U12, U14<br>b) Prior competition season | | | NMT warm-up program during pre-season to improve lower limb balance and maximal muscular power (15-20 minutes program, twice a week during 8 weeks, consisting of 10 exercises) | a) Adherence reported by attendance to the program, recorded by each ski-clubs' designated personnel over the 8-weeks. Each participant was to attend a total of 16 sessions<br>b) Adherence: 34%; loss to follow-up: 28% | |
| Kazumi G et al., 2020[111]<br>Prospective cohort study | to share our experience and challenges as rescue team, investigate the incidence of injury during YOG 2020, and compare it to previous reports. | a) n=155<br>b) F78, M77<br>c) Range 15-18 | a) WOG event<br>b) Winter season | a) IOC consensus statement definitions[52]<br>b) Electronic report forms in the WOG events[52] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Kiers K et al., 2022[112]<br>Prospective cohort and test-retest study<br>Switzerland | to study the test-retest reliability of DPSI assessments using a ski-specific jump protocol that consists of single-leg landings on a three dimensional force plate after forward-performed double-leg drop jumps from a box over a hurdle (DJSLLs); to provide reference values for female and male youth competitive alpine skiers; to explore their changes in DPSI over 3 years during adolescence; and to investigate potential associations of DPSI with age and biological maturation. | a) n=76<br>b) F30, M46<br>c) 13.7 ± 0.6 | a) U16<br>b) Prior competition season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Kiers K et al., 2021[29]<br>Cross-sectional study (descriptive) | to update experts' priorities of perceived key injury risk factor categories in alpine ski racing based on a framework derived 10 years ago; to assess potential priority differences among expert subgroups in dependency of their stakeholder roles the level of competition at which they operate; to identify additional emerging risk factors; and to compile a list with countermeasure suggestions for all risk factors reported. | a) n=532 | a) WC-level, EC-level, FIS-competitions level<br>b) Off-season | | | | | Experts' perceptions on key injury risk factors in alpine ski racing depend on the stakeholder role and differ between the competition levels (WC, EC, FIS competitions). 5 expert stakeholder groups and different level and professional background from 28 countries:<br>- Alpine ski racers (n=298 from WC-, EC-, and FIS competitions levels);<br>- Coaches (n=130 from WC-, EC-, and FIS competitions levels);<br>- Team medical staff (n=59 including doctors, physiotherapists, and other professionals);<br>- Ski racing supplier representatives (n=33 including service men, research & development and management, and other professionals); and<br>- FIS representatives (n=12 including FIS staff for competitions, committee members, and other representatives) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Köhne M et al., 2022[113]<br>Prospective cohort study<br>Germany | to describe the winter sports nation Germany injuries in alpine ski racing and mass sports in terms of statistics and injury mechanisms in winter sports and current trends in sports science. | a) n=105 | a) WC-, and EC-level (all disciplines)<br>b) Season: in- and off-season | b) Smartabase software (German National team)[113] | | | | |
| Kröll J et al., 2016[114]<br>Experimental field study | to provide the decision makers of FIS with an evidence-based foundation for equipment specification changes in giant slalom (GS) by verifying the achievability of the following goal: GS specific injury prevention by a reduction of the ski's aggressiveness, and maintaining the external attractiveness of ski technique to spectators. | a) Exp 1: n=13; Exp 2: n=7<br>b) M | a) Exp1: EC- and WC-levels; Exp2: WC-level (GS)<br>b) Winter season | | | Reduction of kinetic energy with longer skis with higher sidecut radius and reduced profile width in GS. Greater sidecut radius relates to a reduction in subjective perceived aggressiveness | | |
| Kröll J et al., 2016[115]<br>Experimental field study | to investigate the effect of sidecut radius on the characteristics of kinetic energy within a multigate section in giant slalom (GS). | a) n=5<br>b) M | a) EC-level (GS)<br>b) Winter season | | | Reducing kinetic energy by 5.6 to 8.8% with skis with higher sidecut radius both | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | on flat and steep terrain in GS | | |
| Kröll J et al., 2017[18]<br>Editorial | to discuss a recently implemented preventive measure in alpine ski racing as an example; to highlight the influence of sample size and effect size on study power and the possibility for statistical hypothesis testing; and to provide a solution to increase study power for comparable injury prevention initiatives in elite sports. | | a) WC-level | | | Introduction of new equipment rules by FIS for the 2012–2013 season: Longer skis with less-shaped skis (higher sidecut radius) and reduced profile width | | |
| Lagerstrand K et al., 2021[116]<br>Retrospective cohort study (secondary analysis)<br>Sweden | to evaluate if there are differences in thoraco-lumbar disc characteristics between young elite skiers with diverse physical training histories and between young skiers and a non-athletic control group using novel quantitative MRI analysis. | a) n=58<br>b) F28, M30<br>c) 18.2 ± 1.1 | a) Young elite skiers | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Maxwell N et al., 2020[117]<br>Editorial and qualitative study<br>Switzerland | to better understand alpine ski racing athletes' perceptions, beliefs and experiences of sports-related concussion. | a) n=11 | a) Competitive level | | | (1) Educating athletes on sports-related concussion to recognise the presence of SRC and the importance of communicating symptoms of SRC and reduce the threat of premature return-to-play; and (2) educating coaches and supporting staff on their understanding of SRC for the athletes' decision-making process and accompanying athletes in their return-to-play process. | | Athletes representing Swiss-Ski. Sports-related concussion (SRC) is the most frequent head injury in alpine ski racing. Major shortfalls in alpine ski racing athletes' understanding of SRC were identified in the areas of: (1) the definition of concussion; (2) athletes' awareness of the connection between SRC and affective symptom; (3) diagnostic tools; and (4) athletes' understanding of the reasoning behind graduated return-to-play protocols. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mildner E et al., 2010[118]<br>Cross-sectional study<br>Austria | to analyse the influence of ski boots on balance performance of alpine skiers. | a) n=76<br>b) F33, M43<br>c) Students (F 23.8±1.6, M 24.9±2.6); Skiers (F 16.9±1.1, M 16.8±1.1) | a) Youth level<br>b) Prior competition season | | | | | |
| Mössner M et al., 2009[119]<br>Experimental lab study | to investigate the influence of ski stiffness on the trajectory of the skier performing a sequence of turns. | | | | | Skis with reduced torsional stiffness relates to larger penetration depth into the snow due to larger edge angles, reducing skidding and turn radius | | |
| Müller E et al., 2016[120]<br>Editorial | | | | | | Introduction of new equipment rules by FIS for the 2012–2013 season: longer skis with less-shaped skis (higher sidecut radius) and reduced profile width | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Müller L et al., 2017[121]<br>Prospective cohort study<br>Austria | to develop a user-friendly training-and-injury database as the basis for prospective and reliable data collection; and to prospectively assess the incidence, prevalence, and severity of traumatic and overuse injuries, as well as illnesses, of elite youth ski racers with regard to sex, biological maturity status, and relative age should be performed. | a) n=82<br>b) F31, M51<br>c) F: 11.8 ± 1.3; M: 11.6 ± 1.5 | a) Junior level<br>b) Multiple school years | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | | | |
| Müller L et al., 2017[122]<br>Prospective cohort study<br>Austria | to investigate intrinsic risk factors for injuries such as anthropometrics, biological maturity status, physical fitness and ski racing technique among youth ski racers younger than 15 years of age. | a) n=81<br>b) F31, M50<br>c) 11.6 ± 1.4 | a) Junior level<br>b) Multiple school years | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Nabhan D et al., 2019[123]<br>Prospective cohort study<br>United States of America | to describe injury and illness incidence during the 2018 Winter Olympic Games (WOG) by Team USA. | a) n=22<br>b) F10, M12<br>c) Mean 27 (Range 18-39) | a) WOG event<br>b) Winter season | a) Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) IOC injury surveillance system for multisport events[52] | | | | |
| O'Neill DF 2008[124]<br>Qualitative study<br>United States of America | to evaluate whether non-injured peers of athletes who experience an ACL injury exhibit higher levels of negative affect and emotions than athletes who do not have an injured teammate; and whether athletes with injured teammates are at higher risk for injury than those without injured teammates. | a) n=459<br>b) F182, M277<br>c) Range 13-19 | a) Youth level | | | | | |
| Ogrin J et al., 2021[125]<br>Experimental field study | to determine whether asymmetries in basic muscular strength are related to the GRFs encountered during elite slalom skiing. | a) n=9<br>b) M<br>c) 22.7 ± 3.4 | a) EC-level (SL)<br>b) Winter season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Palmer D et al., 2021[126]<br>Prospective cohort study | to describe injury and illness characteristics among participating athletes during the Lausanne 2020 Youth Olympic Winter Games. | a) n=1783 (all)<br>b) F869, M914<br>c) 16.6 ± 1.0 | a) U18, U16, U15 (all disciplines)<br>b) Winter season | a) IOC consensus statement definitions[52]<br>b) Electronic report forms in the WOG events[52] | | | | |
| Palmer-Green D et al., 2014[127]<br>Prospective cohort study<br>Great Britain | to identify the prevalence, severity, nature and causes of athlete injury and illness for the Great Britain Olympic Team (TeamGB) during the Sochi 2014 Winter Olympic Games. | a) n=2 (Alpine skiing only) | a) WOG event<br>b) Winter season | a) Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) The Great Britain Injury/Illness Performance Project (IIPP)[128] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Peterhans L et al., 2020[129]<br>Cross-sectional study<br>Switzerland | to describe the prevalence of overuse-related MRI findings in the lumbar spine of youth competitive alpine skiers of the under 16-years (U16) category with respect to sex- and sex-specific differences in height growth; to assess the associations between MRI findings and biological maturation-dependent multifidus size; to investigate the relationship of MRI findings with age; and to compare the MRI findings of asymptomatic and symptomatic athletes and to explore their clinical relevance. | a) n=108<br>b) F42, M66<br>c) 14.83 ± 0.58 | a) U16<br>b) Season: in- and off-season | a) OSTRC definitions[49,50]; Other and tailored definitions[129]<br>b) OSTRC questionnaire on health problems[49,50] | | | | |
| Petrone N et al., 2012[130]<br>Experimental lab study | to develop a full-scale impact test method suitable for safety barriers commonly installed during Ski World Cup events. | | a) WC-level | | | Design and development of high standard safety net systems | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Petrone N et al., 2008[131]<br>Experimental lab study | to develop a full-scale test method for performing impact tests under controlled conditions on the safety barriers usually adopted during the ski world cup events at the arrival arena. | | a) WC-level | | | Design and development of safety net systems for the arrival arena | | |
| Piat SC et al., 2010[132]<br>Retrospective cohort study | to describe the organization and provision of medical care in the Torino 2006 Winter Olympic Games in light of the epidemiology of illnesses and injuries among athletes during this event. | a) n=323<br>b) F38%, M62% | a) WOG event<br>b) Winter season | a) Other and tailored definitions[132]<br>b) Tailored questionnaire forms[132] | | | | |
| Platzer HP et al., 2021[133]<br>Case study<br>Austria | to assess the effect of the FIS equipment regulations of the years 2003, 2007 and 2012 on severe injury incidence. | a) n=1725 (WC n=727; EC n=536, Junior n=462)<br>b) F774, M951<br>c) Junior to adults | a) WC-level, EC-level and Junior (all disciplines)<br>b) Multiple seasons | a) Other and tailored definitions: severe injury[133]<br>b) Paper-and-pencil questionnaire ; Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | Evaluation of the introduced new equipment rules by FIS in 2002/2003, 2006/2007 and 2011/2012 | | Data analysed over four time periods in males and females from the Austrian Ski Federation:<br>(1) 2001-2003 seasons in all competition levels;<br>(2) 2004-2007 seasons in all competition levels;<br>(3) 2008-2012 seasons in World Cup and Europa Cup athletes, and 2008-2013 in National junior athletes; |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | (4) 2013-2017 seasons in World Cup and Europa Cup athletes, and 2014-2017 seasons in National junior athletes. Seasons beginning May 1st and ending April 30th of the following year. A higher significant incidence of the total severe injury events in the four seasons after the 2002/2003 equipment regulation introduction (greater sidecut radius in downhill skis in both sexes and reduced ski boot sole thickness in males) |
| Raschner C et al., 2012[134] Retrospective cohort study Austria | to determine the relationship between ACL injuries and internal risk factors. | a) n=370 b) F175, M195 c) Range 14-19 | a) Youth level b) Multiple seasons | | | | | |
| Ruedl G et al., 2016[135] Prospective cohort study | to evaluate the incidence and frequencies of injuries and illnesses occurring during the 12th Winter European Youth Olympic Festival (W-EYOF). | a) n=899 (all) b) F333, M566 c) 17.1 ± 0.8 | a) WEYOF (WOG event) b) Winter season | a) IOC consensus statement definitions[52] b) IOC injury surveillance system for multisport events[52] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ruedl G et al., 2012[136]<br>Prospective cohort study | to evaluate the incidence and frequencies of injury and illnesses occurring during the first Winter Youth Olympic Games in Innsbruck in 2012. | a) n=120<br>b) F56, M64<br>c) 16.6 ± 0.9 | a) YWOG (WOG event)<br>b) Winter season | a) IOC consensus statement definitions[52]<br>b) IOC injury surveillance system for multisport events[52] | | | | |
| Russo C et al., 2022[137]<br>Experimental lab study<br>Italy | to propose a wearable IMU-based monitoring system for the evaluation of the ski run to improve athlete performances, and provide the coach qualitative data to support his evaluation. | a) n=6<br>b) F1, M5<br>c) Range 22-37 | a) WC-level (GS, SL)<br>b) Winter season | | | | | |
| Schindelwig K et al., 2014[138]<br>Experimental field study | the development of a simulation model to predict the injury hazard of jumps in downhill ski races. | | a) WC-level<br>b) Winter season | | | | | |
| Schmitt KU et al., 2016[139]<br>Retrospective cohort study (using historical data)<br>Switzerland | to investigate retrospectively whether physical fitness is associated with knee injury history, especially ACL rupture. | a) n=70<br>b) F38, M32<br>c) 15.1 ± 2.1 | a) Elite athletes (all disciplines) | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Schoeb T et al., 2022[140]<br>Experimental field study<br>Switzerland | to introduce a novel injury prevention programme targeted to the specific injury patterns of youth competitive alpine skiers of the U16 category, hereinafter called ISPAInt (short for "Injury Screening and Prevention—Alpine Skiing"); and to compare the differences in injury occurrence between an intervention group additionally performing the ISPAInt programme once a week over a 12-month period in their real-world training setting and age-matched controls following their regular training routines. | a) n=129 (IG n=71, CG n=58)<br>b) Female/male ratio: IG=0.82, CG=0.81<br>c) 14.4 ± 0.3 | a) U16<br>b) Multiple seasons | a) OSTRC definitions[49,50]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | Training programme: alpine skiing-specific injury mechanisms programme (ISPAint programme): 20-min home training programme, once a week during one year, consisting of three exercise families: eccentric hamstring strength, leg axis stability by strengthening external hip rotators, and trunk stability. | a) Participants' adherence to this recommendation was surveyed but not enforced. The IG participants' adherence to the ISPAInt programme was assessed by an additional question attached to the OSTRC questionnaire.<br>b) Adherence rate: 0.8 ± 0.6 sessions/week; dropouts due to quitting sports career in the enrolment procedure: 29% | U16 alpine skiers from the Swiss-Ski (certified regional performance centre [RLZ/CRP] of Swiss-Ski, representing the best skiers of their age) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Schoeb T et al., 2020[141]<br>Prospective cohort study<br>Switzerland | to investigate the prevalence of the health problems typically occurring in youth competitive alpine skiers by the use of the OSTRC questionnaire and with respect to sex, chronological age, and season differences; to describe their duration, severity, and location; and to assess the relationship between biological maturation and the occurrence and severity of health problems. | a) n=155 (U15 n=77; U14 n=78)<br>b) F59, M96<br>c) 13.89 ± 0.60 | a) U15, U14<br>b) Season: in- and off-season | a) OSTRC definitions[49,50]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | |
| Soligard T et al., 2019[5]<br>Prospective cohort study | to describe the incidence and characteristics of the sports injuries and illnesses occurring during the PyeongChang 2018 Olympic Winter Games. | a) n=2914 (all)<br>b) F1210, M1704 (all) | a) WOG event<br>b) Winter season | a) IOC consensus statement definitions[52]<br>b) IOC injury surveillance system for multisport events[52] | | | | |
| Soligard T et al., 2015[142]<br>Prospective cohort study | to analyse and describe the injury and illness rates and characteristics in the Sochi 2014 Olympic Winter Games. | a) n=314<br>b) F130, M184 | a) WOG event<br>b) Winter season | a) IOC consensus statement definitions[52]<br>b) IOC injury surveillance system for multisport events[52] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spiess J et al., 2019[143]<br>Case-control study<br>Switzerland | to establish whether the hamstrings of alpine ski racers show eccentric strength deficits following surgery on the anterior cruciate ligament. | a) n=88 (70+18)<br>b) F40, M48 - F29, M41 - F11, M7<br>c) 19.72 ± 3.35 | a) Elite level<br>b) Precompetitive season | | | | | |
| Spörri J et al., 2010[144]<br>Qualitative study | to generate, together with the other ISS projects, a comprehensive discussion basis for short term regimens in terms of specific risk factors and mechanisms behind injuries. | a) n= 63: athletes (n=12), coaches (n=19), officials/race organisers (n=12), representatives ski equipment companies (n=10), topic specific experts (n=10) | a) WC-level<br>b) Winter season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spörri J et al., 2012[13]<br>Qualitative study | to compile a list of perceived intrinsic and extrinsic risk factors for severe injuries in alpine WC ski racing; and to derive precise qualitative statements about those factors that are thought to have the highest impact on injury risk in order to provide more detailed hypotheses for further studies. | a) n= 61: Athletes (allrounders n=7, speed n=3, technical n=1), Coaches (n=30), Officials/race organisers (n=11), representatives ski equipment companies (n=10), topic specific experts (n=10) | a) WC-level (all disciplines)<br>b) Winter season | | | | | |
| Spörri J et al., 2016[145]<br>Experimental field study | to investigate the effect of increased gate offsets on the biomechanical variables related to spinal disc loading in GS and SL; and to compare the aforementioned variables between these competition disciplines. | a) n=10 | a) WC-level and EC-level (GS and SL)<br>b) Winter season | | | Lower back peak GRFs by increasing horizontal gate offset by 50% (from 3 m to 4.5 m) in SL | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spörri J et al., 2018[146]<br>Experimental field study | to assess the effect of reduced standing height on the overall trunk kinematics and occurring ground-reaction forces in alpine GS from an overuse injury prevention perspective. | a) n=7 | a) EC-level (GS)<br>b) Winter season | | | Lower overall back GRF of 2.5% with skis with a 10 mm-lower standing height (20%) in GS | | |
| Spörri J et al., 2017[147]<br>Experimental field study | to describe power spectral density (i.e., the signal's power distribution over frequency) of the vibrations acting on the different body segments in the competition disciplines giant GS and SL; and to quantify and compare the root-mean square (RMS) accelerations acting on the lower back (i.e., the severity of vibration exposure) while skiing GS and SL turns. | a) n=6<br>b) M | a) EC-level (GS and SL)<br>b) Winter season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spörri Jet al., (2016)[148]<br>Experimental field study | to investigate the effect of skis with different sidecut radii on variables related to the mechanics of turning in GS; and to discuss the findings in the context of injury prevention in alpine ski racing. | a) n=6 | a) EC-level (GS)<br>b) Winter season | | | Lower GRF and reduced ski self-steering with skis with higher sidecut radius in GS | | |
| Spörri J et al., 2015[149]<br>Experimental field study | to describe the sport-specific, overall trunk kinematics and skiers' loading during giant slalom (GS) turns; to investigate the general potential to affect the aforementioned factors by external preventive measures, such as the recent changes in the equipment rules of the International Ski Federation (FIS) by comparing "old" GS skis versus "newly regimented" GS skis (longer skis with less width and less sidecut). | a) n=8 | a) EC-level (GS)<br>b) Multiple winter seasons | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spörri J et al., 2012[150]<br>Experimental field study | to investigate the effect of increased horizontal gate distance on energy-related and injury mechanism-related variables in GS. | a) n=1 | a) WC-level (GS) | | | | | |
| Spörri J et al., 2019[151]<br>Editorial | | | | | | Machine-groomed snow preparation to reduce low-frequency whole-body vibrations and acting back GRFs in SL | | |
| Spörri J et al., 2022[152]<br>Experimental field study | to biomechanically describe the corresponding ACL injury case from a functional perspective and in comparison to "normal" reference skiing. | a) n=1<br>b) M<br>c) 30 | a) EC-level (GS)<br>b) Winter season | | "Slipping edge-catch" | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spörri J et al., 2021[153]<br>Editorial | to emphasize the relationship between health, performance, and technology, and to highlight current challenges in the design of innovative measuring systems, wearable sensors, and assessment protocols for examining and monitoring health and performance in sports like Freestyle, Alpine, Nordic and Paralympic skiing. It was also intended to compile research articles focusing on the application of digitalization and technology in the context of performance enhancement, injury prevention, and rehabilitation. | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| St-Onge N et al., 2004[154]<br>Experimental lab study | to evaluate the effect of the position of the pivot point on ACL strain and thus on the chances of tearing the ligament; and to evaluate the effect of binding release characteristics on ACL strain. | | | | | | | |
| Stainsby B et al., 2014[155]<br>Cross-sectional study (descriptive)<br>Canada | to explore the attitudes and actions of Canadian alpine ski racing coaches regarding spinal protective devices. | a) n=29<br>b) F and M | a) Canadian Ski Coaches Federation | | | | b) Only 23% of the 126 coaches fully responded. | Canadian provincial alpine skiing racing coaches through Canadian Ski Coaches Federation training athletes aged 10-15. Lack of use of spinal protective devices (51.7% do not actively enforce their use), and lack of guidelines and policies regarding their use (80% reported ignorance or unawareness of specific guidelines or policies). |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Steenstrup SE et al., 2017[156]<br>Case series | to analyse head and face injuries recorded by the FIS Injury Surveillance System (ISS) through 10 seasons (2006–2016) of WC alpine and freestyle skiing and snowboarding to describe their mechanisms. | a) n=29<br>c) 27.0 ± 5.7 | a) WC-level and WOG event (DH, SG, GS, SL)<br>b) Winter season | a) Fuller CW et al., definitions[45,46]; Other and tailored definitions[156] | Head and face: After turning or landing after a jump. Ski racers rolling, yawing and/or pitching. | | | |
| Steenstrup SE et al., 2014[157]<br>Cross-sectional study<br>United States of America, Austria, Canada, Finland, France, Germany, Italy, Switzerland, Norway, Sweden | to investigate the incidence of head injuries, including the severity and the types of injuries, in the different alpine, freestyle and snowboarding disciplines, in addition to examining any sex differences in head injury risk. | a) n=1880<br>b) F832, M1048 | a) WC-level (all disciplines)<br>b) Winter season | a) Fuller CW et al., definitions[45,46]<br>b) FIS Injury Surveillance System (ISS) based on annual retrospective interviews[19] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Steenstrup SE et al., 2017[158]<br>Case series | to describe the injury mechanisms in a selection of head impact injury cases meeting our inclusion criteria among WC alpine skiers; to describe the gross head impact biomechanics; and to compare the head impact kinematics with relevant helmet standards. | a) n=7<br>b) F3, M4 | a) WC-level and WOG event (DH and SG)<br>b) Winter season | | Head: ski racers pitching backwards (1-2) or pitching forward or backwards in a spiralling motion (3). | | | |
| Steffen K et al., 2017[159]<br>Prospective cohort study | to describe and analyse the injury and illness rates, as well as their characteristics in the 2nd Youth Olympic Winter Games, held in Lillehammer in 2016. | a) n=1083<br>b) F502 (46%), M581 (54%)<br>c) F 16.6 ± 1.0; M 16.9 ± 0.9 | a) U18, U16, U15<br>b) Winter season | a) IOC consensus statement definitions[52]<br>b) IOC injury surveillance system for multisport events[52] | | | | |
| Steidl-Müller L et al., 2018 - study 1[160]<br>Cross-sectional study<br>Austria | to assess the influence of age-related performance levels on the LSI in high-level, competitive, non-injured athletes to assess the natural range of LSI. | a) n=285 (Youth n=95; Adolescent n=107; Elite n=83)<br>b) Youth: F39, M56; Adolescent: F47, M60; Elite: F39, M44<br>c) Youth: 11.9 ± 1.1; Adolescent: 16.3 ± 1.4; | a) Youth level (youth and adolescent), elite level (WC-, EC-, FIS competitions levels)<br>b) Prior competition season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Elite: 21.5 ± 3.1 | | | | | | |
| Steidl-Müller L et al., 2018 - study 2[160]<br>Prospective cohort study<br>Austria | to prospectively assess limb differences as a possible risk factor for traumatic and overuse injury in youth ski racers. | a) n=67<br>b) F25, M43<br>c) F: 12.3 ± 1.1; M: 12.0 ± 1.2 | a) Youth level<br>b) Multiple seasons | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) IOC injury surveillance system for multisport events[52] | | | | |
| Steidl-Müller L, Hildebrandt C, Müller E, et al (2020)[161]<br>Prospective cohort study<br>Austria | to investigate prospectively the role of biological maturity status, and changes in anthropometric characteristics, as well as changes in physical fitness parameters over one season in the context of injury risk identification in elite youth ski racers younger than 15 years of age. | a) n=89<br>b) F39, M50<br>c) 12.1 ± 1.3 | a) Youth level<br>b) Winter season | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]<br>b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Steidl-Müller L et al., 2020[162]<br>Prospective cohort study<br>Austria | to investigate prospectively over a period of 4 seasons the role of biological maturity status, body weight, and body height percentiles and core flexion to extension strength ratios in the context of traumatic and overuse injury risk identification in elite youth ski racers from the ages of 10 years at the beginning of the observation period. | a) n=72<br>b) F27, M45<br>c) 10.6 ± 0.3 (Range 10-14) | a) Youth level<br>b) Season: in- and off-season | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | | | |
| Stenroos AJ et al., 2014[163]<br>Retrospective cohort study<br>Finland | to retrospectively investigate the injury patterns and rates in Finland at the competition level of alpine skiing taking place both in races and in trainings, and to pilot a continuous competition alpine skiing injury survey in Finland. | a) n=1322<br>b) F463, M859<br>c) 82%: 9-15, 18%: adults | a) Competitive level (SL, GS, SG)<br>b) Multiple seasons | a) Other and tailored definitions: acute injury[163]<br>b) Tailored form of interview and questionnaire[163] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Stern C et al., 2020[164]<br>Prospective cohort study (secondary analysis)<br>Switzerland | to investigate the prevalence of distal femoral cortical irregularities at the femoral tendon attachment of the medial and lateral head of the gastrocnemius muscle (LHG) and of the adductor magnus muscle in youth competitive alpine skiers compared with young adults of the same age. | a) n=210 (IG n=105; CG n=105)<br>b) F39, M66 (CG: F46, M59)<br>c) 14.8 ± 0.6 (CG: 14.6 ± 0.5) | a) Young athletes<br>b) Winter season | | | | | |
| Strutzenberger G et al., 2022[165]<br>Cross-sectional study<br>Switzerland | to investigate the implementability of the DBB exercise in 6- to 15-year-old competitive alpine skiers and to determine their DBB performance as a function of age group and sex; to investigate the associations of DBB performance with age, anthropometrics and maturity offset. | a) n=101 (U10 n=50; U15 n=61)<br>b) F58, M43 (U10= F31, M19; U15= F27, M24)<br>c) Range 6-15 | a) U10, U15<br>b) Off-season | | | Deadbug bridging (DBB) exercise: antirotation and rear-chain stabilization capacity. | | 6-to 15-year-old Swiss competitive alpine skiers taking part of a physical fitness competition during the 2021 off-season period. Prior the event, participants had access to a video tutorial to practice and be familiarised with the DBB exercise. DBB is a low dynamic closed-chain stabilization exercise addressing typical components of mechanisms leading to back overuse injuries in alpine ski racing. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Supej M et al., 2015[166]<br>Cross-sectional study | to determine the influence of the steepness of the slope on kinematic and kinetic variables during a slalom ski race. | a) n=10<br>b) M<br>c) 26.9 ± 2.5 | a) WC-level (SL)<br>b) Winter season | | | | | |
| Supej M et al., 2019[167]<br>Commentary | to provide an update on the biomechanics of alpine ski racers and their equipment. | | a) WOG event (all disciplines)<br>b) Winter season | | | | | |
| Supej M et al., 2018[168]<br>Experimental field study | to examine whole-body vibrations connected with different types of skiing and the associated potential risk of developing low back pain. | a) n=8 | a) Former competitive level (SL)<br>b) Winter season | | | | | |
| Supej M et al., 2017[20]<br>Editorial | | | | | | Improve safety by improving the safety-release in ski bindings and the planning and regulation of terrains and courses in competitions | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tang W et al., 2022[169]<br>Case report study | to analyse the components and dynamic characteristics of alpine skiing; to construct an "Object-Characteristic-Relation" representation model to express multi-level knowledge; and to propose a "Characteristic value-Relationship" representation method based on the multisource data to construct the knowledge graph of alpine skiing. | | a) WOG event<br>b) Winter season | | | Suspension of events when temperatures are higher than 2ºC or lower than -25ºC, or showers with a strong wind faster than 15 m/s | | |
| Tecklenburg K et al., 2007[170]<br>Case report study | to describe first case of an acute anterior cruciate ligament deficiency combined with simultaneous locked bucket-handle tears of both medial and lateral menisci in an athlete including injury mechanism, clinical symptoms, specific signs on | a) n=1<br>b= F<br>c) 19 | a) (DH)<br>b) Winter season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | MRI, and treatment options. | | | | | | | |
| Todd C et al., 2018[171]<br>Cross-sectional study (descriptive)<br>Sweden | to evaluate the relationship between the lifetime prevalence of back pain and hip pain among young elite skiers and to correlate these findings and compare them to a non-athletic age matched control group. | a) n=75<br>b) F35, M40<br>c) 18.2 ± 1.1 | a) Youth level | b) Tailored questionnaire forms[171] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tudor A et al., 2003[172]<br>Case report study<br>Croatia | to explore the mechanisms of intra-articular calcaneal fractures in young competing skiers, as well as to emphasize the possibility of an unusual and severe foot injury despite the use of sophisticated ski equipment and excellent physical fitness. | a) n=1<br>b) M<br>c) 14 | a) Youth level (GS)<br>b) Winter season | | | | | |
| Verdaguer A et al., 2021[173]<br>Prospective cohort study<br>Andorra | to determine the stress recovery levels in high-performance alpine ski athletes based on the level of internal load at three times of the season. | a) n=7<br>b) F<br>c) 19.43 ± 4.08 | a) FIS Competitions level (Super-G)<br>b) Winter season | b) Tailored questionnaire forms[173] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| von Rosen P et al., 2018[174]<br>Prospective cohort study<br>Sweden | to identify the injury burden in a cohort of elite adolescent athletes in multiple sports by following these athletes weekly during 1 calendar year. To describe the injury patterns in terms of injury type, location, prevalence or incidence, recurrence, and severity grade; time to first injury; and prevalence of illness; and to compare differences in injury data by sex and sport type. | a) n=5<br>c) Median 17, range 15-19 | a) Youth level<br>b) Winter season | a) Other and tailored definitions: injury, physical complaints and illness[174]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | | | | |
| Watanabe K et al., 2018[175]<br>Prospective cohort study<br>Asia | to describe medical services provided by the 2017 AWG and report injuries and illnesses occurred therein. | a) n=1550 | a) Stakeholders: physicians, nurses, physiotherapists, athletic trainers, ambulance crew, ski patrols.<br>b) Winter season | b) Electronic report forms in the WOG events[52] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Westin M et al., 2012[176]<br>Prospective cohort study<br>Sweden | to study the injury profile in terms of injury incidence, injury location and type of injury as well as injury severity in alpine skiers at the Swedish Ski High schools and also to study possible gender differences. | a) n=431<br>b) F216, M215<br>c) 16.7 ± 1.1 | a) Youth level<br>b) Multiple seasons | a) Fuller CW et al., definitions[45,46]<br>b) Tailored questionnaire forms[176] | | | | |
| Westin M et al., 2018[177]<br>Case-control study<br>Sweden | to study potential intrinsic and extrinsic risk factors for ACL injuries in competitive adolescent alpine skiers between 16 and 20 years of age. | a) n=339<br>b) F163, M176<br>c) ACL: 17.6 ± 1.1; Non-ACL: 17.7 ± 1.2 | a) Youth level<br>b) Multiple seasons | | | | | |
| Westin M et al., 2020[178]<br>Prospective cohort study (intervention study with historical controls)<br>Sweden | to evaluate whether a sports specific prevention program including different exercises could reduce the incidence of ACL injuries in competitive adolescent alpine skiers. | a) n=736 (IG n=305; CG n=431)<br>b) IG: F157, M148; CG: F216, M215<br>c) IG: 17.1 ± 1.14; CG: 17.5 ± 1.23 | a) Youth level (GS and SL)<br>b) Multiple seasons | | | Educational and exercise-based ACL injury prevention video program. First year: watching the video every third week during preseason and once a month during competition season. Three indoor | a) Compliance was collected through a questionnaire<br>b) 42% answered the questionnaire about their compliance and 75% watched the video 1-5 times | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | and three on-snow exercises on core stability and neuromuscular control. | | |
| Westin M et al., 2022[179] Prospective cohort study Sweden | to investigate possible intrinsic risk factors for an ACL reinjury in young competitive alpine skiers during their ski high school years; and to describe this sub cohort of students from a health perspective using the RAND 36-Item health survey 1.0. | a) n=384 (n=31) b) F193, M191 (F26, M5) c) 16.5 ± 0.5 | a) Youth level b) Prior competition season | a) Other and tailored definitions[179] b) Tailored questionnaire forms[179] | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Westin M et al., 2022[180]<br>Cross-sectional (descriptive) and test-retest study<br>Sweden | to develop a screening instrument consisting of five questions regarding side dominance in competitive adolescent alpine skiers; to conduct a survey identifying side dominance; and to study whether competitive adolescent alpine skiers had a safer/better ski turn to the left or to the right and if this was correlated with side dominance. | a) n=274 (survey) - n=121 (test-retest)<br>b) F144, M130 (survey) - F59, M62 (test-retest)<br>c) 17.7 ± 1.4 | a) Youth level<br>b) Off-season | | | | | |
| Westin M et al., 2016[181]<br>Cross-sectional study (descriptive)<br>Sweden | to investigate whether there is any relationship between the prevalence of ACL injuries in alpine ski students at elite level and ACL injuries in their parents. | a) n=593<br>b) F293, M300<br>c) 20.5 ± 2.6 | a) Youth level | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Witwit WA et al., 2018[182]<br>Cross-sectional study<br>Sweden | to identify MRI changes in the thoraco-lumbar spine and the lifetime prevalence of back pain, as well as the association between them, in young elite skiers compared to a non-athletic control group. | a) n=59<br>b) F47%, M53%<br>c) 18.2 ± 1.1 | a) Youth level | a) Other and tailored definitions[182]<br>b) Tailored questionnaire forms[182] | | | | |
| Wolfsperger F et al., 2015[183]<br>Cross-sectional (descriptive), experimental field and lab study | to quantify snow conditions and their spatial and temporal variation within each monitored track as well as to detect differences between the seven analysed WC races. | a) n=3 observers, n=50 athletes | a) WC-level (DH, GS)<br>b) Winter season | | | | | |
| Yamazaki J et al., 2015[184]<br>Case series | to estimate head impact velocities in a crash at a World Cup downhill skiing event that resulted in the athlete suffering a severe TBI, using a model-based image matching (MBIM) technique; and to demonstrate the utility of this method for future implementation in a cohort study of | a) n=1<br>b) M<br>c) 30 | a) WC-level (DH)<br>b) Winter season | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ski crash incidents. | | | | | | | |
| Zorko M et al., 2015[185] Experimental field study Slovenia | to establish how the knee-joint kinematics changes during a skiing turn, using skis with different waist widths. | a) n=6 c) 23.33 ± 3.44 | a) Youth and former competitors (course similar to GS) b) Winter season | | | | | |

**Supplementary information 3: Characteristics of the included studies – providing context across studies**

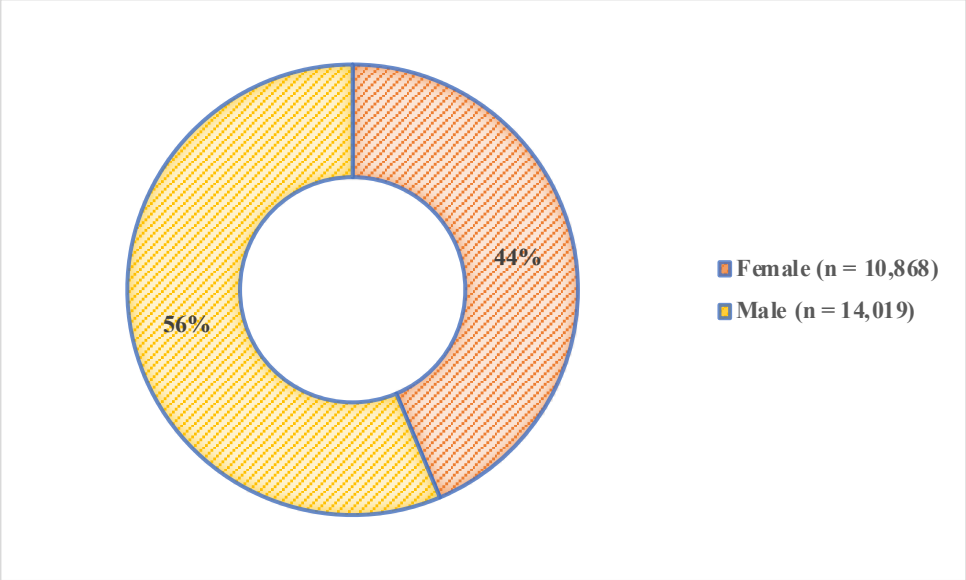


**Fig 1** Gender distribution of the sample of the included studies.

**Table 1** Classification of the study designs of the included studies.

| Study design | | | | Number of studies (n) |
|---|---|---|---|---|
| **Quantitative** | **Observational** | | | |
| | | **Descriptive** | Case study | 3 |
| | | | Case report | 4 |
| | | | Case series | 9 |
| | | | Cross-sectional | 11 |
| | | *Total* | | *27* |
| | | **Analytical** | Case-control | 7 |
| | | | Cohort | 50 |
| | | | Cross-sectional | 24 |
| | | *Total* | | *80* |
| | *Total* | | | 108 |
| | **Experimental** | | Field | 18 |

| | | | |
|---|---|---|---|
| | | Lab | 13 |
| | *Total* | | *31* |
| | | *Prospective* | 43 |
| | | *Retrospective* | 8 |
| *Total* | | | 139 |
| **Qualitative** | | Qualitative | 4 |
| | *Total* | | 4 |
| **Other study designs** | | Commentary | 1 |
| | | Consensus | 1 |
| | | Editorial | 7 |
| | | Methodological study | 1 |
| | | Pilot study | 3 |
| | | Quasi-experimental | 1 |
| | | Test-retest study | 2 |
| | | Time-trend analysis | 1 |
| | *Total* | | *17* |
| **Documents** | | Manual | 3 |
| | *Total* | | 3 |

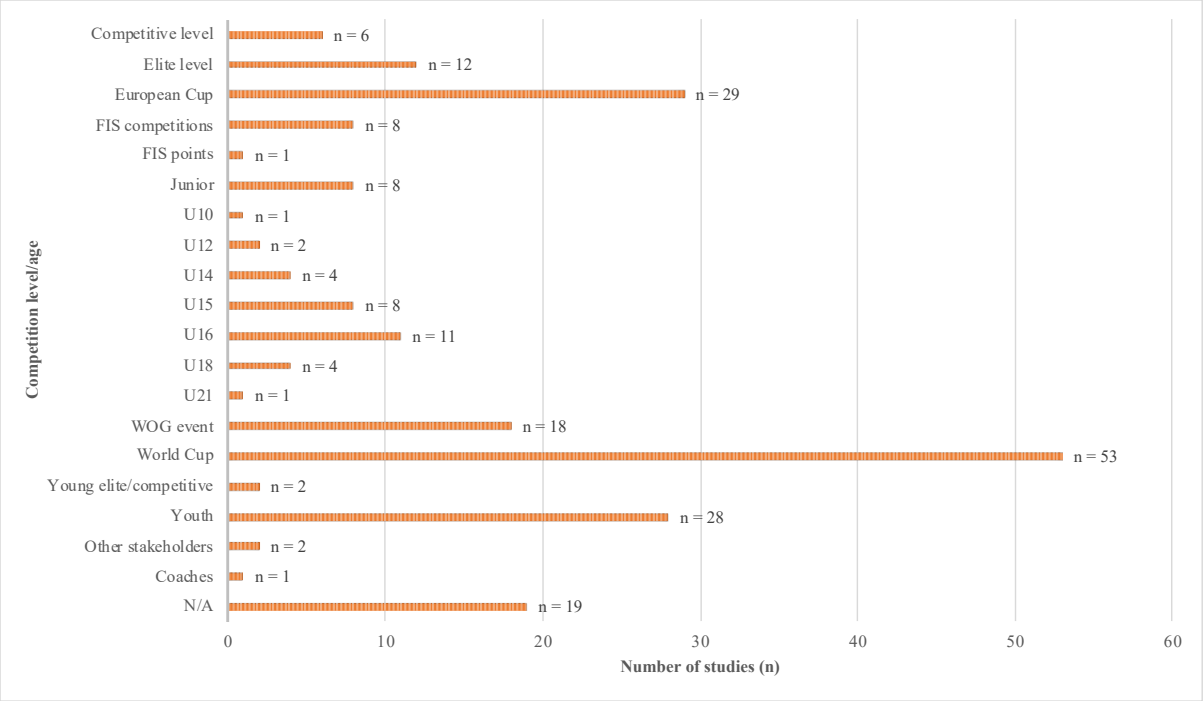


**Fig 2** Competition level and age distribution across the included studies. *FIS: International Ski and Snowboarding Federation; WOG: Winter Olympic Games.*

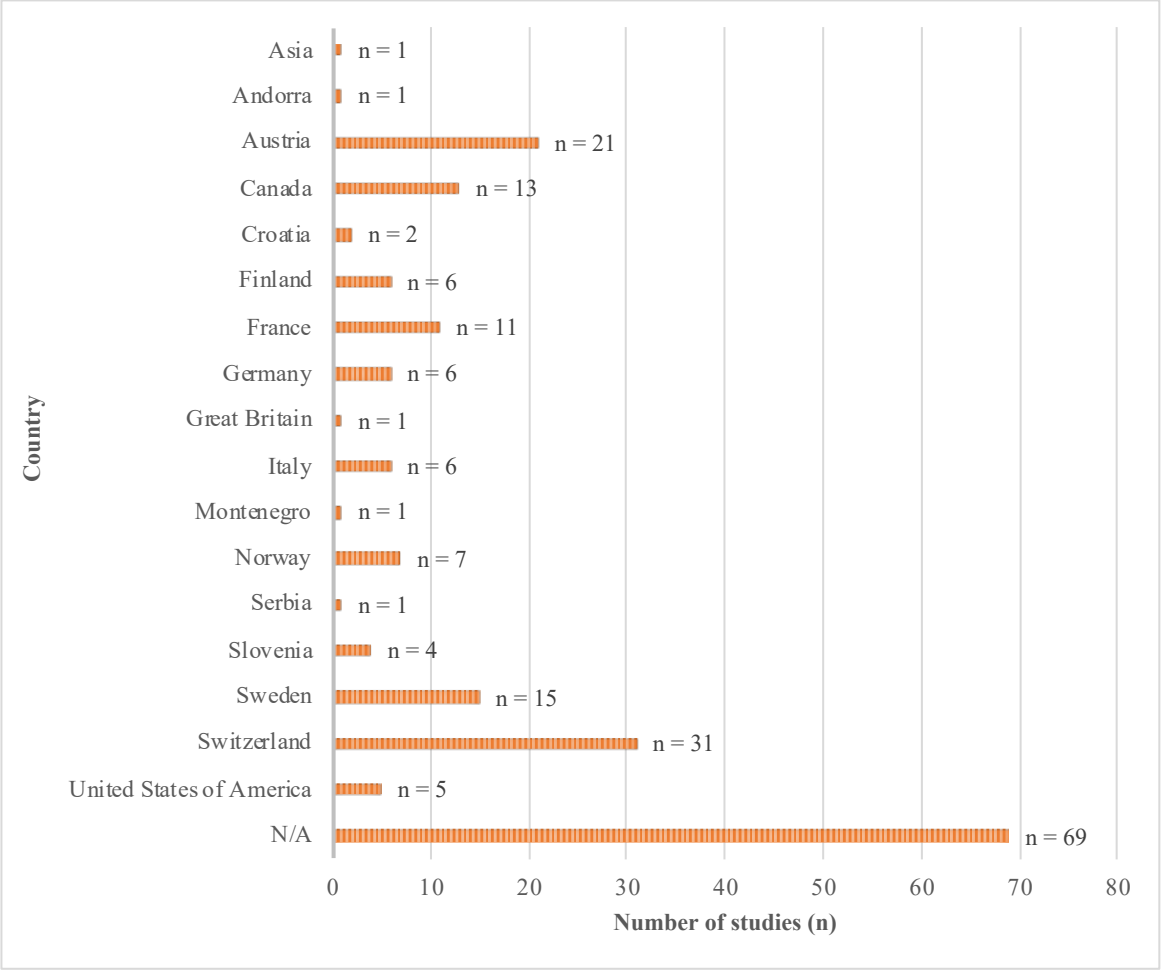


**Fig 3** Country and federation distribution across the included studies.

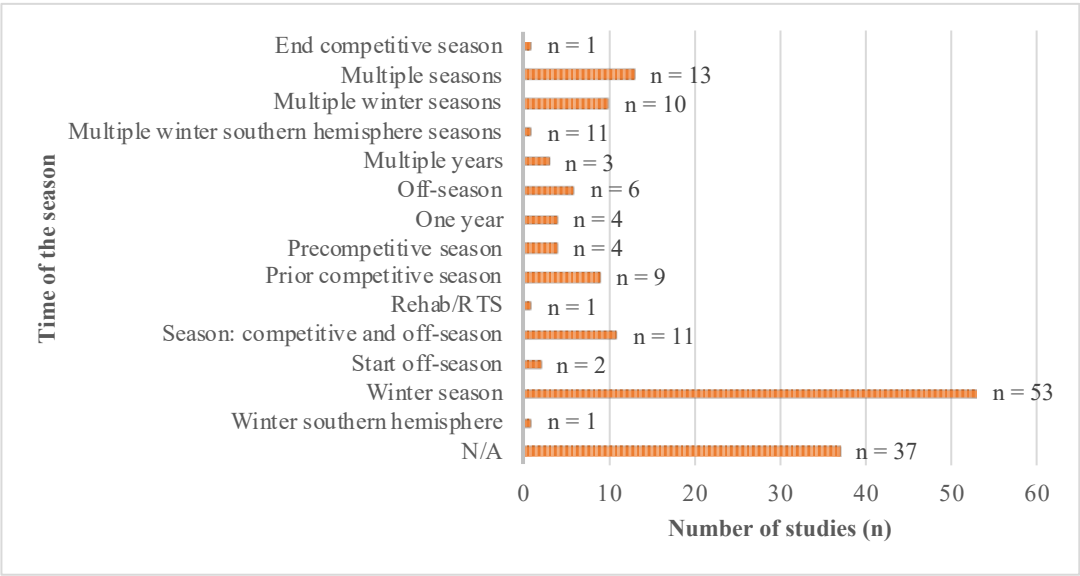

**Fig 4** Time of the season distribution across the included studies. *RTS: return-to-sport.*

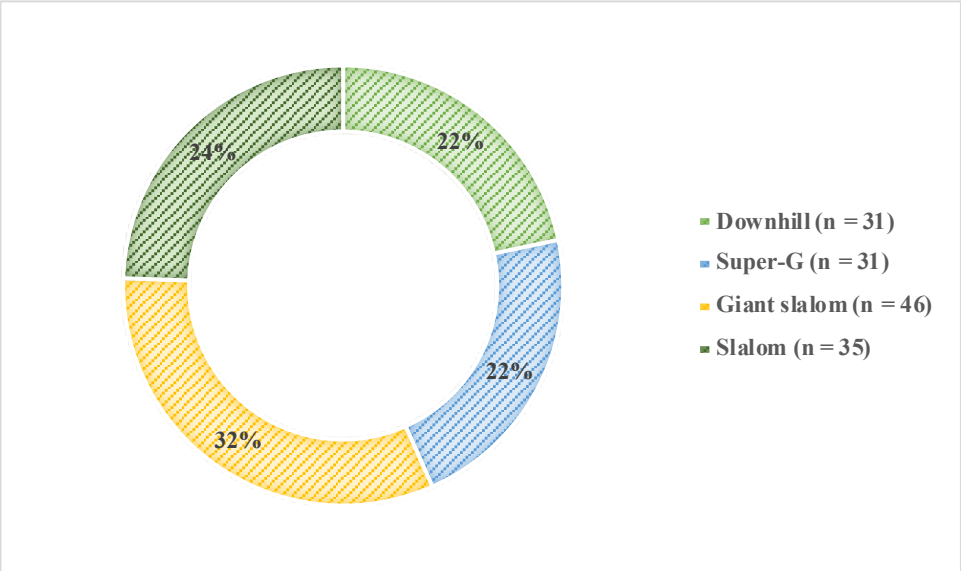


**Fig 5** Alpine skiing disciplines distribution across the included studies.

**Supplementary information 4: TRIPP Stage 1 – Injury surveillance**

**Table 1** Data extraction of the included studies in stage 1 of the TRIPP framework. *ACL: anterior cruciate ligament; AWG: Asian Winter Games; CC: control group; DH: downhill; DJ: drop jump; EC: European Cup; F: female/s; FIS: International Ski and Snowboarding Federation; GS: giant slalom; IG: intervention group; IOC: International Olympic Committee; ISS: Injury Surveillance System; M: male/s; MRI: magnetic resonance imaging; OSTRC: Oslo Sports Trauma Research Centre; PT: patellar tendon; RR: risk ratio/s; RTS: return-to-sport; SG: Super-G; SL: slalom; TD: team doctor; US: ultrasound; WC: World Cup; WOG: Winter Olympic Games.*

| **Study features** | **Aim of the study** | **Sample characteristics** | **Study context** | **Injury data** |
|---|---|---|---|---|
| **Author, year, study design, country/federation** | | **a) Sample size (n)**<br>**b) Gender**<br>**c) Age** | **a) Competition level (alpine skiing discipline)**<br>**b) Time of the season/year** | **a) Injury definition**<br>**b) Injury reporting method** |
| Alhammoud M et al., 2020[1]<br>Prospective cohort study<br>France | to prospectively investigate the rate and pattern of injuries over 5 years among competitive European Cup alpine skiers and to compare winter competitive season with the summer off-season. | a) n=133<br>b) F54, M79<br>c) 20.8 ± 2.7 | a) EC-level<br>b) Multiple seasons | a) Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.*<br>b) Tailored questionnaire forms[1] |
| Alhammoud M et al., 2021[44]<br>Prospective cohort study<br>France | to characterise the thermoregulatory responses of elite alpine skiers during their activity. | a) n=4 (staff n=6)<br>b) M<br>c) 28 ± 6 | a) WC-level and Olympic medalists (GS and SL)<br>b) Winter season | |

| | | | | |
|---|---|---|---|---|
| Bachmann C et al., 2008[48]<br>Cross-sectional study (descriptive)<br>Switzerland | to investigate the level-specific prevalence of upper extremity injuries. | a) n=87<br>b) F24, M63<br>c) F20.7 ± 3.9, M22.8 ± 4.8 | a) WC-, EC-, FIS competitions and youth levels<br>b) Multiple seasons | a) Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.*<br>b) OSTRC questionnaire on health problems (and on-site interviews)[49,50] |
| Barth M et al., 2022[51]<br>Prospective cohort study<br>Austria | to describe the incidence per 1000 runs and sex-specific RR of in-competition severe injury events (SIEcomp) in elite alpine ski racing; to examine the change in the seasonal SIEcomp incidence per 1000 runs over 24 seasons; and to compare the SIEcomp incidence per 1000 runs and the respective sex-specific RR in downhill, super-G, giant slalom, and slalom. | a) n=2333 (WC n=963; EC n=732; Junior n=638)<br>b) F1042, M1291<br>c) Junior to adults | a) WC-level, EC-level and Junior (all disciplines)<br>b) Multiple seasons | a) Other and tailored definitions – severe injury:[51]<br>*When the absence from training and/or competition lasted longer than five weeks.*<br>b) Paper-and-pencil questionnaire; Online questionnaire (Austrian Ski Team) - Internet-based database[2] |
| Barth M et al., 2020[2]<br>Prospective cohort study<br>Austria | to describe the incidence and gender-specific risk ratio of acute on-snow severe injury events (SIE) in elite alpine ski racing; to examine the development of the severe injury events incidence over 22 seasons; and to analyse the SIE with respect to the severely injured body parts and body structures. | a) n=2225 (WC n=921; EC n=696; Junior n=608)<br>b) F994, M1231<br>c) Junior to adults | a) WC-level, EC-level, Junior (all disciplines)<br>b) Season: in- and off-season | a) IOC consensus statement definitions:[52]<br>*Injury: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*Overuse injury: An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*Noncontact trauma: A traumatic event without contact with another athlete or object, such as a fall.*<br>b) Paper-and-pencil questionnaire; Online questionnaire (Austrian Ski Team) - Internet-based database[2] |
| Bere T et al., 2014[9]<br>Cross-sectional study<br>Austria, Canada, Finland, France, Germany, Italy, Norway, Sweden, Switzerland, Slovenia | to compare the risk of injury in female versus male World Cup (WC) alpine skiers, based on 6-year data from the FIS ISS. | a) n=1593<br>b) F708, M885 | a) WC-level (all disciplines)<br>b) Multiple winter seasons | a) Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention"* |

| | | | | |
|---|---|---|---|---|
| | | | | *injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.* *Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.* |
| | | | | b) FIS Injury Surveillance System (ISS) based on annual retrospective interviews[19] |
| Bergstrom KA et al., 2001[55] Prospective cohort study Norway | to report the amount of overuse injuries, malalignment, and indistinct knee pain in athletic adolescents aged 15–19 years at a ski high school. | a) n=14 b) F8, M6 c) Mean 17 (Range 15-19) | a) Youth level b) 1 year | a) Other and tailored definitions – knee complaints:[55] *Overuse injuries: defined as tendinitis, periostitis, or similar conditions as a result of repetitive minor trauma or overuse.* *Malalignment: defined as tibial torsion, increased Q-angle, subluxation or tilting of the patella, patella alta or baja.* *"Indistinct knee pain": those cases where we did not find any causal connection between clinical or radiographic findings and the localised pain reported.* |
| Bergstrom KA et al., 2004[56] Prospective cohort study Norway | to explore the relationships between different type of skiing and activity levels to overuse injuries, small abnormalities, and back pain alone in growing athletes from 15 through 19 years attending a Norwegian ski high school | a) n=14 b) F8, M6 c) Mean 17 (Range 15-19) | a) Youth level b) 1 year | a) Other and tailored definitions: back complaints[56] *Overuse injury: as secondary scoliosis (functional scoliosis caused by larger unilateral torque forces developed in particular activities), apophyseal microtrauma and herniated or extruded disc.* *Small abnormality: as spina bifida occulta, large transverse process of L5 and sacroileitis.* *"Low back pain": when no other cause of back pain was present.* |
| Bielmeier CM et al., 2021[57] Cross-sectional study (descriptive) United States of America | to establish detailed information about ski laceration injuries among adolescent and young adult US ski racers, on (a) the frequency, severity, and body location of laceration injuries during skiing and (b) the skiing environment and ski maintenance method used at the time of the laceration injury. | a) n=249 b) F50%, M50% c) Range 10-24 | a) Junior and elite level (all disciplines) b) Off-season | b) Retrospective survey [57] |
| Carraro A et al., 2020[59] Cross-sectional study Italy | to describe the demographics, sports exposure, and other sports- or warm-up-related practices of adolescent competitive alpine skiers; to assess the prevalence of lower back complaints in this specific cohort with respect to sex, category, and discipline preference; to explore their lower back complaints severity (i.e., intensity and | a) n=188 (U16 n=128; U18 n=60) b) F78, M110 c) F: 16.0 ± 1.0; M: 16.1 ± 1.1 | a) U16, U18 b) End of competitive season | a) Other and tailored definitions[59] |
| | | | | b) Tailored questionnaire forms[59] |

| | | | | |
|---|---|---|---|---|
| | disability); and to investigate the potential relations with training attributes. | | | |
| Csapo R et al., 2018[62]<br>Retrospective cohort study | to analyse the fitness level of convalescent elite alpine skiers after completion of physical rehabilitation (5–6 months post-surgery) and the changes in competition performance after return to sports. | a) n=46<br>b) F26, M20<br>c) F: 20.0 ± 2.7; M: 21.6 ± 3.2 | a) WC-level, Continental Cup-level, FIS competitions level [CC: EC and Nor-Am Cup]<br>b) Rehab/RTS | b) Tailored questionnaire forms[62] |
| Csapo R et al., 2020[63]<br>Prospective cohort and pilot study<br>Austria | to investigate potential changes in the anterior cruciate ligament (ACL) structure of alpine ski racers over the course of an entire season using quantitative magnetic resonance imaging (T2 mapping). | a) n=4<br>b) M<br>c) Mean 22 | a) EC-level and WC-level (SL, GS)<br>b) Season: in- and off-season | |
| Doyle-Baker PK et al., 2020[65]<br>Cross-sectional study (descriptive)<br>Canada | to describe the participation of all sport and physical activity by type and volume, and the secondary aim was to provide insight into the injuries reported and health indicators (health care utilisation, illness, medication use) in adolescent youth ski club racers in Western Canada. | a) n=96<br>b) F52, M44<br>c) 11.5 ± 1.1 (range: 9.3-13.7) | a) Youth level | a) Other and tailored definitions – concussion:[65]<br>*Concussion: either diagnosed or not or been "knocked out" or had their "bell rung").*<br>*Non-concussive injury: requiring medical attention or at least 1 day of missed participation in the past 12 months).*<br>b) Tailored questionnaire on concussions (Canada)[65] |
| Engebresten L et al., 2010[71]<br>Prospective cohort study | to describe the risk of injury and illnesses occurring during the XXI Winter Olympic Games in Vancouver 2010. | a) n=308<br>b) F133, M175 | a) WOG<br>b) Winter season | a) IOC consensus statement definitions:[52]<br>*Injury: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*Overuse injury: An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*Noncontact trauma: A traumatic event without contact with another athlete or object, such as a fall.*<br>b) IOC injury surveillance system for multisport events[52] |
| Fitze DP et al., 2022[73]<br>Prospective cohort study<br>Switzerland | to provide reference values regarding lumbar multifidus morphology of female and male youth competitive alpine skiers; to investigate the influence of biological maturation on lumbar multifidus | a) n=85 (U16 n=45, U15 n=40)<br>b) F28, M57<br>c) F14.7 ± 0.7, M14.9 ± 0.5 | a) U16, U15 (youth level)<br>b) One year | a) Other and tailored definitions: overuse-related back complaints[73]<br>*Substantial injury: moderate or severe reductions in training volume and/or sports performance, and/or complete inability to participate in sports.* |

| | | | | |
|---|---|---|---|---|
| | morphology; to verify whether lumbar multifidus morphology is associated with DBB performance; and to compare the lumbar multifidus morphology of symptomatic and asymptomatic skiers and examine the potential clinical relevance of these findings. | | | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] |
| Fitze DP et al., 2022[74]<br>Prospective cohort study<br>Switzerland | to describe biceps femoris long head morphology in youth competitive alpine skiers with respect to sex, age and maturity offset; and to investigate its association with the occurrence of traumatic injuries of the lower extremities in the upcoming season. | a) n=95<br>b) F33, M62<br>c) F14.7 ± 0.6; M14.9 ± 0.7 | a) Youth level | a) Fuller CW et al., definitions:[45,46]<br>*<u>Injury:</u> Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*<u>Recurrent injury:</u> An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.*<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] |
| Florenes TW et al., 2009[8]<br>Cross-sectional study<br>Austria, Canada, Finland, France, Germany, Italy, Norway, Sweden, Switzerland, Slovenia | to describe the risk of injury and the injury pattern among competitive World Cup alpine skiers during the competitive season. | a) n=521<br>b) F229, M292 | a) WC-level (all disciplines)<br>b) Multiple winter seasons | a) Fuller CW et al., definitions:[45,46]<br>*<u>Injury:</u> Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*<u>Recurrent injury:</u> An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.*<br>b) Retrospective interviews[8] |
| Florenes TW et al., 2011[19]<br>Methodological study<br>Switzerland, Germany, France, Finland, Canada, Norway | to compare three different methods to record injuries among World Cup skiers and snowboarders, prospective reporting by the TD, prospective reporting by the medical staff of selected World Cup teams and retrospective interviews with World | a) n=141 | a) WC-level (all disciplines)<br>b) Winter season | a) Fuller CW et al., definitions:[45,46]<br>*<u>Injury:</u> Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.* |

| | | | | |
|---|---|---|---|---|
| | Cup athletes at the end of the World Cup season. | | | *Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.* |
| | | | | b) Retrospective interviews; Prospective injury reports from the team doctor; Prospective injury reports (medical team registration)[19] |
| Florenes TW et al., 2012[75] Cross-sectional study Germany, Switzerland, Canada, Finland, France, Norway, Italy, Sweden, Austria | to describe the injury risk and injury pattern among World Cup athletes in alpine skiing, freestyle skiing, snowboarding, ski jumping, cross country skiing and Nordic combined based on data from the FIS ISS. | a) n=521 (alpine skiing)<br>b) F229, M292 | a) WC-level (all disciplines)<br>b) Winter season | a) Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.* |
| | | | | b) Retrospective interviews[75] |
| Fröhlich S et al., 2021[3] Prospective cohort study Switzerland | to estimate the injury risks for a national team cohort among female and male competitive alpine skiers during the off-season preparation and competition periods based on a prospective approach and an "any complaint" injury definition; and to describe the patterns of traumatic and overuse injuries with respect to injury severity, body location and injury type. | a) n=44<br>b) F25, M19<br>c) 21.4 ± 2.8 | a) WC-level, EC-level, FIS competitions level<br>b) Season: in- and off-season | a) Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.* |
| | | | | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] |
| Fröhlich S et al., 2020[77] Prospective cohort study Switzerland | to prospectively investigate the prevalence and severity of knee-related, back-related and hip-related overuse injuries in top female elite alpine skiers during the off-season preparation period; and to assess the relationship of knee complaints with traumatic preinjuries and the total training hours. | a) n=26 (SL-GS n=15; SG-DH n=11)<br>b) F<br>c) 20.91 ± 2.67 | a) Elite athletes (all disciplines)<br>b) Off-season | a) OSTRC definitions:[49,50]<br>*Overuse injury: Any physical complaint that was not attributable to a single identifiable event and caused time loss from full participation in training.*;<br>Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a* |

| | | | | |
|---|---|---|---|---|
| | | | | *player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.* *Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.* |
| | | | | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] |
| Fröhlich S et al., 2020[78] Cross-sectional study Switzerland | to describe the knee overuse-related clinical complaints and MRI abnormalities in a cohort of youth competitive alpine skiers around the growth spurt. | a) n=108 b) F 42, M66 c) 14.83 ± 0.58 | a) Youth level b) 1 year | a) Other and tailored definitions[78] |
| | | | | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] |
| Fröhlich S et al., 2020[79] Case report study | to describe a case of medial malleolar bursitis in a competitive alpine skier, which, to our knowledge, has not been previously reported. | a) n=1 b) M c) 23 | a) Competitive level | |
| Gallo-Vallejo MA et al., 2017[80] Prospective cohort study | to analyse and describe the injuries and diseases suffered during the 27th Winter Sports Universiade held in February 2015 in Granada and Sierra Nevada, Spain. | a) n=174 (Alpine skiing only) b) F70, M104 | a) WSU (WOG event) b) Winter season | a) IOC consensus statement definitions:[52] *Injury: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.* *Overuse injury: An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.* *Noncontact trauma: A traumatic event without contact with another athlete or object, such as a fall.* |
| | | | | b) Tailored questionnaire forms[80] |

| | | | | |
|---|---|---|---|---|
| Götschi T et al., 2022[88]<br>Prospective case-control study<br>Switzerland | to examine the quantitative patellar tendon (PT) properties (morphological and mechanical) shear of the PT using quantitative B-mode US and 3D mapping of SWV in a large athletic cohort of youth competitive alpine skiers as a function of demographic factors; to identify distinct regional PT properties of skiers with distal and/or proximal PT complaints vs. skiers with healthy PTs; and to compare the sensitivity and specificity of this novel US SWE approach with the diagnostic accuracy of MRI as the gold standard approach to detect PT complaints. | a) n=106<br>b) F40, M66<br>c) Range 13-15 | a) Youth level | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] |
| Götschi T et al., 2022[89]<br>Case-control study<br>Switzerland | to investigate differences in PT SWV in competitive alpine skiers compared to age-matched healthy control subjects; to evaluate sex-specific differences in PT SWV; and to describe potential differences in regional SWV patterns in both cohorts. | a) n=30<br>b) F14, M16<br>c) 23.6 ± 2.50 | a) Elite level<br>b) Off-season | b) OSTRC questionnaire on health problems[49,50] |
| Han PD et al., 2022[90]<br>Prospective cohort study | to evaluate the characteristics and frequencies of injury and illnesses occurring among all athletes during the Beijing 2022 Olympic Winter Games. | a) n=2897 (all)<br>b) F1304, M1593 (all) | a) WOG event<br>b) Winter season | a) IOC consensus statement definitions:[52]<br>*Injury: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*Overuse injury: An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*Noncontact trauma: A traumatic event without contact with another athlete or object, such as a fall.*<br>b) Tailored form of interview and questionnaire[90] |
| Hildebrandt C et al., 2019[96]<br>Prospective cohort study<br>Austria | to develop a user-friendly training-and-injury database as the basis for prospective and reliable data collection. | a) n=82<br>b) F31, M51<br>c) F: 11.8 ± 1.3; M: 11.6 ± 1.5 | a) Junior level<br>b) Multiple school years | b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] |

| | | | | |
|---|---|---|---|---|
| Hildebrandt C et al., 2021[97]<br>Prospective cohort study<br>Austria | to prospectively examine training load as it relates to the occurrence, severity, and burden of injuries and illnesses in youth alpine ski racers. | a) n=91<br>b) F39, M52<br>c) F: 12.0 ± 1.3; M: 12.1 ± 1.0 (range 10-14) | a) Youth level<br>b) Season: in- and off-season | a) Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.*<br>b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] |
| Hildebrandt C et al., 2013[98]<br>Cross-sectional study<br>Austria | to investigate the profile of ski specific injuries over a two-year period in a cohort of youth alpine skiers from a special sport boarding school who compete in high-level sports. Of particular interest was the comparison of overuse and traumatic injuries during the winter and summer seasons. | a) n=104<br>b) F43, M61<br>c) Range 15-18 | a) Youth level<br>b) Multiple seasons | a) Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.;*<br>IOC consensus statement definitions:[52]<br>*Injury: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*Overuse injury: An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*Noncontact trauma: A traumatic event without contact with another athlete or object, such as a fall.*<br>b) Retrospective interviews[98] |

| | | | | |
|---|---|---|---|---|
| Holden WM et al., 2022[99]<br>Case series | to describe a case series of these injuries in order to increase awareness and encourage further studies on injury mechanisms and prevention. | a) n=5<br>b) F2, M3<br>c) Median 16 (Range 15-20) | a) (SL, SG, GS)<br>b) Winter season | |
| Javet M et al., 2022[103]<br>Cross-sectional study<br>Switzerland | to explore reasonable application purposes and potential confounders of the SSPT in youth competitive alpine skiers. | a) N=144 (U16 n=31, U15 n=81, U14 n=32)<br>b) F57, M87 (F: U16 n=9, U15 n=34, U14 n=14; M: U16 n=22, U15 n=47, U14 n=18)<br>c) 14.5 (14.3–14.6) | a) U16, U15, U14<br>b) Prior competition season | a) Fuller CW et al., definitions:[45,46]<br>*<u>Injury:</u> Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*<u>Recurrent injury:</u> An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.* |
| | | | | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] |
| Jedvaj H et al., 2021[104]<br>Cross-sectional study (descriptive)<br>Croatia, Slovenia, Serbia and Montenegro | to examine the level of kinesiophobia in skiers who have sustained knee injuries. | a) n=33<br>b) F22, M11<br>c) 24 ± 7.4 | a) Competitive skiing for 14.7 ± 5.4 years (all disciplines)<br>b) Winter season | a) Other and tailored definitions[104] |
| | | | | b) Retrospective survey[104] |
| Jordan MJ et al., 2017[108]<br>Case series<br>Canada | to evaluate the concurrent pathologies, including meniscal tears, chondral lesions, and multiligament injuries, at the time of primary ACLR in elite alpine ski racers; to evaluate the future state of the chondral lesions and meniscal tears; and to evaluate the occurrence of ACL reinjury in elite alpine ski racers by reviewing postoperative reports obtained from surgeries that occurred subsequent to the primary ACLR. | a) n=32<br>b) F17, M15 | a) Elite level<br>b) Season: in- and off-season | b) Tailored questionnaire forms[108] |
| Kazumi G et al., 2020[111]<br>Prospective cohort study | to share our experience and challenges as rescue team, investigate the incidence of injury during YOG 2020, and compare it to previous reports. | a) n=155<br>b) F78, M77<br>c) Range 15-18 | a) WOG event<br>b) Winter season | a) IOC consensus statement definitions:[52]<br>*<u>Injury</u>: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.* |

| | | | | |
|---|---|---|---|---|
| | | | | *<u>Overuse injury:</u> An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*<u>Noncontact trauma:</u> A traumatic event without contact with another athlete or object, such as a fall.*<br>b) Electronic report forms in the WOG events[52] |
| Köhne M et al., 2022[113]<br>Prospective cohort study<br>Germany | to describe the winter sports nation Germany injuries in alpine ski racing and mass sports in terms of statistics and injury mechanisms in winter sports and current trends in sports science. | a) n=105 | a) WC-, and EC-level (all disciplines)<br>b) Season: in- and off-season | b) Smartabase software (German National team)[113] |
| Kröll J et al., 2017[18]<br>Editorial | to discuss a recently implemented preventive measure in alpine ski racing as an example; to highlight the influence of sample size and effect size on study power and the possibility for statistical hypothesis testing; and to provide a solution to increase study power for comparable injury prevention initiatives in elite sports. | | a) WC-level | |
| Lagerstrand K et al., 2021[116]<br>Retrospective cohort study (secondary analysis)<br>Sweden | to evaluate if there are differences in thoraco-lumbar disc characteristics between young elite skiers with diverse physical training histories and between young skiers and a nonathletic control group using novel quantitative MRI analysis. | a) n=58<br>b) F28, M30<br>c) 18.2 ± 1.1 | a) Young elite skiers | |
| Müller L et al., 2017[121]<br>Prospective cohort study<br>Austria | to develop a user-friendly training-and-injury database as the basis for prospective and reliable data collection; and to prospectively assess the incidence, prevalence, and severity of traumatic and overuse injuries, as well as illnesses, of elite youth ski racers with regard to sex, biological maturity status, and relative age should be performed. | a) n=82<br>b) F31, M51<br>c) F: 11.8 ± 1.3; M: 11.6 ± 1.5 | a) Junior level<br>b) Multiple school years | a) OSTRC definitions:[49,50]<br>*<u>Overuse injury:</u> Any physical complaint that was not attributable to a single identifiable event and caused time loss from full participation in training.*;<br>Fuller CW et al., definitions:[45,46]<br>*<u>Injury:</u> Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.* |

| | | | | |
|---|---|---|---|---|
| | | | | *<u>Recurrent injury:</u> An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.;*<br>IOC consensus statement definitions:[52]<br>*<u>Injury</u>: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*<u>Overuse injury:</u> An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*<u>Noncontact trauma:</u> A traumatic event without contact with another athlete or object, such as a fall.* |
| | | | | b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] |
| Nabhan D et al., 2019[123]<br>Prospective cohort study<br>United States of America | to describe injury and illness incidence during the 2018 Winter Olympic Games (WOG) by Team USA. | a) n=22<br>b) F10, M12<br>c) Mean 27 (Range 18-39) | a) WOG event<br>b) Winter season | a) Fuller CW et al., definitions:[45,46]<br>*<u>Injury:</u> Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*<u>Recurrent injury:</u> An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.;*<br>IOC consensus statement definitions:[52]<br>*<u>Injury</u>: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*<u>Overuse injury:</u> An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*<u>Noncontact trauma:</u> A traumatic event without contact with another athlete or object, such as a fall.* |
| | | | | b) IOC injury surveillance system for multisport events[52] |

| | | | | |
|---|---|---|---|---|
| Palmer D et al., 2021[126]<br>Prospective cohort study | to describe injury and illness characteristics among participating athletes during the Lausanne 2020 Youth Olympic Winter Games. | a) n=1783 (all)<br>b) F869, M914<br>c) 16.6 ± 1.0 | a) U18, U16, U15 (all disciplines)<br>b) Winter season | a) IOC consensus statement definitions:[52]<br>*Injury: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*Overuse injury: An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*Noncontact trauma: A traumatic event without contact with another athlete or object, such as a fall.*<br>b) Electronic report forms in the WOG events[52] |
| Palmer-Green D et al., 2014[127]<br>Prospective cohort study<br>Great Britain | to identify the prevalence, severity, nature and causes of athlete injury and illness for the Great Britain Olympic Team (TeamGB) during the Sochi 2014 Winter Olympic Games. | a) n=2 (Alpine skiing only) | a) WOG event<br>b) Winter season | a) Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.;*<br>IOC consensus statement definitions:[52]<br>*Injury: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*Overuse injury: An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*Noncontact trauma: A traumatic event without contact with another athlete or object, such as a fall.*<br>b) The Great Britain Injury/Illness Performance Project (IIPP)[128] |

| | | | | |
|---|---|---|---|---|
| Peterhans L et al., 2020[129]<br>Cross-sectional study<br>Switzerland | to describe the prevalence of overuse-related MRI findings in the lumbar spine of youth competitive alpine skiers of the under 16-years (U16) category with respect to sex- and sex-specific differences in height growth; to assess the associations between MRI findings and biological maturation-dependent multifidus size; to investigate the relationship of MRI findings with age; and to compare the MRI findings of asymptomatic and symptomatic athletes and to explore their clinical relevance. | a) n=108<br>b) F42, M66<br>c) 14.83 ± 0.58 | a) U16<br>b) Season: in- and off-season | a) OSTRC definitions:[49,50]<br>*<u>Overuse injury:</u> Any physical complaint that was not attributable to a single identifiable event and caused time loss from full participation in training.*;<br>Other and tailored definitions[129] |
| | | | | b) OSTRC questionnaire on health problems[49,50] |
| Piat SC et al., 2010[132]<br>Retrospective cohort study | to describe the organisation and provision of medical care in the Torino 2006 Winter Olympic Games in light of the epidemiology of illnesses and injuries among athletes during this event. | a) n=323<br>b) F38%, M62% | a) WOG event<br>b) Winter season | a) Other and tailored definitions[132] |
| | | | | b) Tailored questionnaire forms[132] |
| Ruedl G et al., 2016[135]<br>Prospective cohort study | to evaluate the incidence and frequencies of injuries and illnesses occurring during the 12th Winter European Youth Olympic Festival (W-EYOF). | a) n=899 (all)<br>b) F333, M566<br>c) 17.1 ± 0.8 | a) WEYOF (WOG event)<br>b) Winter season | a) IOC consensus statement definitions:[52]<br>*<u>Injury</u>: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*<u>Overuse injury:</u> An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*<u>Noncontact trauma:</u> A traumatic event without contact with another athlete or object, such as a fall.* |
| | | | | b) IOC injury surveillance system for multisport events[52] |
| Ruedl G et al., 2012[136]<br>Prospective cohort study | to evaluate the incidence and frequencies of injury and illnesses occurring during the first Winter Youth Olympic Games in Innsbruck in 2012. | a) n=120<br>b) F56, M64<br>c) 16.6 ± 0.9 | a) YWOG (WOG event)<br>b) Winter season | a) IOC consensus statement definitions:[52]<br>*<u>Injury</u>: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*<u>Overuse injury:</u> An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.* |

| | | | | |
|---|---|---|---|---|
| | | | | *<u>Noncontact trauma:</u> A traumatic event without contact with another athlete or object, such as a fall.* |
| | | | | b) IOC injury surveillance system for multisport events[52] |
| Schoeb T et al., 2020[141]<br>Prospective cohort study<br>Switzerland | to investigate the prevalence of the health problems typically occurring in youth competitive alpine skiers by the use of the OSTRC questionnaire and with respect to sex, chronological age, and season differences; to describe their duration, severity, and location; and to assess the relationship between biological maturation and the occurrence and severity of health problems. | a) n=155 (U15 n=77; U14 n=78)<br>b) F59, M96<br>c) 13.89 ± 0.60 | a) U15, U14<br>b) Season: in- and off-season | a) OSTRC definitions:[49,50]<br>*<u>Overuse injury:</u> Any physical complaint that was not attributable to a single identifiable event and caused time loss from full participation in training.*; |
| | | | | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] |
| Soligard T et al., 2019[5]<br>Prospective cohort study | to describe the incidence and characteristics of the sports injuries and illnesses occurring during the PyeongChang 2018 Olympic Winter Games. | a) n=2914 (all)<br>b) F1210, M1704 (all) | a) WOG event<br>b) Winter season | a) IOC consensus statement definitions:[52]<br>*<u>Injury</u>: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*<u>Overuse injury:</u> An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*<u>Noncontact trauma:</u> A traumatic event without contact with another athlete or object, such as a fall.* |
| | | | | b) IOC injury surveillance system for multisport events[52] |
| Soligard T et al., 2015[142]<br>Prospective cohort study | to analyse and describe the injury and illness rates and characteristics in the Sochi 2014 Olympic Winter Games. | a) n=314<br>b) F130, M184 | a) WOG event<br>b) Winter season | a) IOC consensus statement definitions:[52]<br>*<u>Injury</u>: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*<u>Overuse injury:</u> An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*<u>Noncontact trauma:</u> A traumatic event without contact with another athlete or object, such as a fall.* |

| | | | | |
|---|---|---|---|---|
| | | | | b) IOC injury surveillance system for multisport events[52] |
| Spörri J et al., 2021[153]<br>Editorial | to emphasise the relationship between health, performance, and technology, and to highlight current challenges in the design of innovative measuring systems, wearable sensors, and assessment protocols for examining and monitoring health and performance in sports like Freestyle, Alpine, Nordic and Paralympic skiing. It was also intended to compile research articles focusing on the application of digitalisation and technology in the context of performance enhancement, injury prevention, and rehabilitation. | | | |
| Steenstrup SE et al., 2014[157]<br>Cross-sectional study<br>United States of America, Austria, Canada, Finland, France, Germany, Italy, Switzerland, Norway, Sweden | to investigate the incidence of head injuries, including the severity and the types of injuries, in the different alpine, freestyle and snowboarding disciplines, in addition to examining any sex differences in head injury risk. | a) n=1880<br>b) F832, M1048 | a) WC-level (all disciplines)<br>b) Winter season | a) Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.*<br>b) FIS Injury Surveillance System (ISS) based on annual retrospective interviews[19] |
| Steffen K et al., 2017[159]<br>Prospective cohort study | to describe and analyse the injury and illness rates, as well as their characteristics in the 2nd Youth Olympic Winter Games, held in Lillehammer in 2016. | a) n=1083<br>b) F502 (46%), M581 (54%)<br>c) F 16.6 ± 1.0; M 16.9 ± 0.9 | a) U18, U16, U15<br>b) Winter season | a) IOC consensus statement definitions:[52]<br>*Injury: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*Overuse injury: An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*Noncontact trauma: A traumatic event without contact with another athlete or object, such as a fall.* |

| | | | | |
|---|---|---|---|---|
| | | | | b) IOC injury surveillance system for multisport events[52] |
| Steidl-Müller L et al., 2020[162]<br>Prospective cohort study<br>Austria | to investigate prospectively over a period of 4 seasons the role of biological maturity status, body weight, and body height percentiles and core flexion to extension strength ratios in the context of traumatic and overuse injury risk identification in elite youth ski racers from the ages of 10 years at the beginning of the observation period. | a) n=72<br>b) F27, M45<br>c) 10.6 ± 0.3 (Range 10-14) | a) Youth level<br>b) Season: in- and off-season | a) OSTRC definitions:[49,50]<br>*Overuse injury: Any physical complaint that was not attributable to a single identifiable event and caused time loss from full participation in training.*;<br>Fuller CW et al., definitions:[45,46]<br>*Injury: Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*Recurrent injury: An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.;*<br>IOC consensus statement definitions:[52]<br>*Injury: Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.*<br>*Overuse injury: An injury resulting from repeated microtrauma without a single, identifiable event responsible for the injury and a traumatic injury refers to one caused by a specific, identifiable event. Overuse injuries are divided into two groups based on the onset of symptoms.*<br>*Noncontact trauma: A traumatic event without contact with another athlete or object, such as a fall.* |
| | | | | b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] |
| Stenroos AJ et al., 2014[163]<br>Retrospective cohort study<br>Finland | to retrospectively investigate the injury patterns and rates in Finland at the competition level of alpine skiing taking place both in races and in trainings, and to pilot a continuous competition alpine skiing injury survey in Finland. | a) n=1322<br>b) F463, M859<br>c) 82%: 9-15, 18%: adults | a) Competitive level (SL, GS, SG)<br>b) Multiple seasons | a) Other and tailored definitions – acute injury:[163]<br>*Injury resulting in a training pause longer than one week.* |
| | | | | b) Tailored form of interview and questionnaire[163] |

| | | | | |
|---|---|---|---|---|
| Stern C et al., 2020[164]<br>Prospective cohort study (secondary analysis)<br>Switzerland | to investigate the prevalence of distal femoral cortical irregularities at the femoral tendon attachment of the medial and lateral head of the gastrocnemius muscle (LHG) and of the adductor magnus muscle in youth competitive alpine skiers compared with young adults of the same age. | a) n=210 (IG n=105; CG n=105)<br>b) F39, M66 (CG: F46, M59)<br>c) 14.8 ± 0.6 (CG: 14.6 ± 0.5) | a) Young athletes<br>b) Winter season | |
| Todd C et al., 2018[171]<br>Cross-sectional study (descriptive)<br>Sweden | to evaluate the relationship between the lifetime prevalence of back pain and hip pain among young elite skiers and to correlate these findings and compare them to a non-athletic age matched control group. | a) n=75<br>b) F35, M40<br>c) 18.2 ± 1.1 | a) Youth level | b) Tailored questionnaire forms[171] |
| Verdaguer A et al., 2021[173]<br>Prospective cohort study<br>Andorra | to determine the stress recovery levels in high-performance alpine ski athletes based on the level of internal load at three times of the season. | a) n=7<br>b) F<br>c) 19.43 ± 4.08 | a) FIS Competitions level (Super-G)<br>b) Winter season | b) Tailored questionnaire forms[173] |
| von Rosen P et al., 2018[174]<br>Prospective cohort study<br>Sweden | to identify the injury burden in a cohort of elite adolescent athletes in multiple sports by following these athletes weekly during 1 calendar year. To describe the injury patterns in terms of injury type, location, prevalence or incidence, recurrence, and severity grade; time to first injury; and prevalence of illness; and to compare differences in injury data by sex and sport type. | a) n=5<br>c) Median 17, range 15-19 | a) Youth level<br>b) Winter season | a) Other and tailored definitions – injury, physical complaints and illness:[174]<br>*Injury: any self-reported physical complaint resulting in difficulties participating in normal training or competition, reduced training volume, pain, or reduced performance in sport related to an injury.*<br>*Substantial injury: any self-reported physical complaint resulting in a moderate or severe reduction in training volume, a moderate or severe reduction in performance, or the complete inability to participate in sports related to an injury.*<br>*Recurrent injury: an injury in the same body site as the previous injury within the last year.*<br>*Illness: a self-reported health problem other than the musculoskeletal system, such as cold or influenza, resulting in reduced training volume or difficulty participating in normal training or competition.*<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] |

| | | | | |
|---|---|---|---|---|
| Watanabe K et al., 2018[175]<br>Prospective cohort study<br>Asia | to describe medical services provided by the 2017 AWG and report injuries and illnesses occurred therein. | a) n=1550 | a) Stakeholders: physicians, nurses, physiotherapists, athletic trainers, ambulance crew, ski patrols.<br>b) Winter season | b) Electronic report forms in the WOG events[52] |
| Westin M et al., 2012[176]<br>Prospective cohort study<br>Sweden | to study the injury profile in terms of injury incidence, injury location and type of injury as well as injury severity in alpine skiers at the Swedish Ski High schools and to study possible gender differences. | a) n=431<br>b) F216, M215<br>c) 16.7 ± 1.1 | a) Youth level<br>b) Multiple seasons | a) Fuller CW et al., definitions:[45,46]<br>*<u>Injury:</u> Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical attention" injury, and an injury that results in a player being unable to take a full part in future football training or match play as a "time loss" injury.*<br>*<u>Recurrent injury:</u> An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury.*<br>b) Tailored questionnaire forms[176] |
| Westin M et al., 2022[179]<br>Prospective cohort study<br>Sweden | to investigate possible intrinsic risk factors for an ACL reinjury in young competitive alpine skiers during their ski high school years; and to describe this sub cohort of students from a health perspective using the RAND 36-Item health survey 1.0. | a) n=384 (n=31)<br>b) F193, M191 (F26, M5)<br>c) 16.5 ± 0.5 | a) Youth level<br>b) Prior competition season | a) Other and tailored definitions[179]<br>b) Tailored questionnaire forms[179] |
| Witwit WA et al., 2018[182]<br>Cross-sectional study<br>Sweden | to identify MRI changes in the thoraco-lumbar spine and the lifetime prevalence of back pain, as well as the association between them, in young elite skiers compared to a non-athletic control group. | a) n=59<br>b) F47%, M53%<br>c) 18.2 ± 1.1 | a) Youth level | a) Other and tailored definitions[182]<br>b) Tailored questionnaire forms[182] |

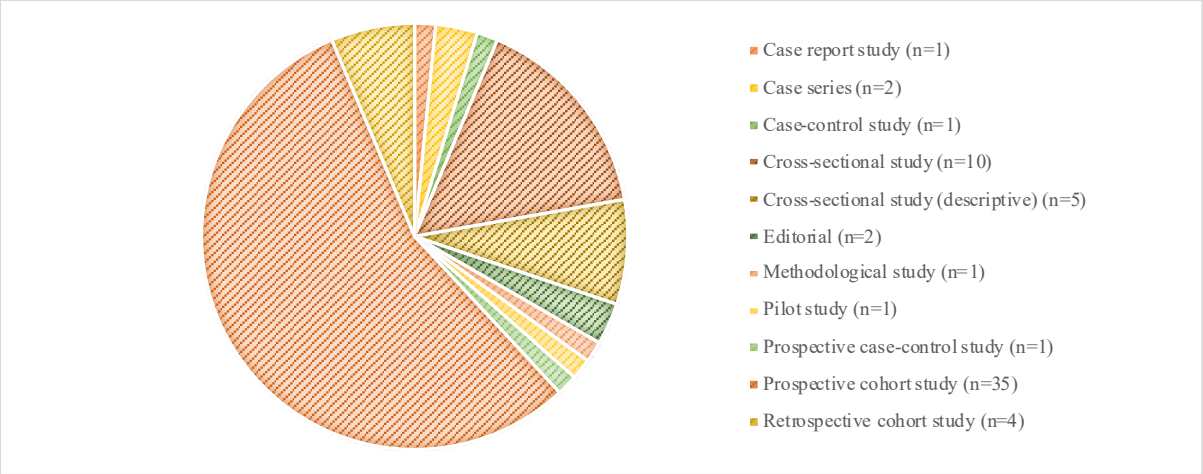


**Fig 1** Study designs of the included studies in stage 1 of the TRIPP framework.

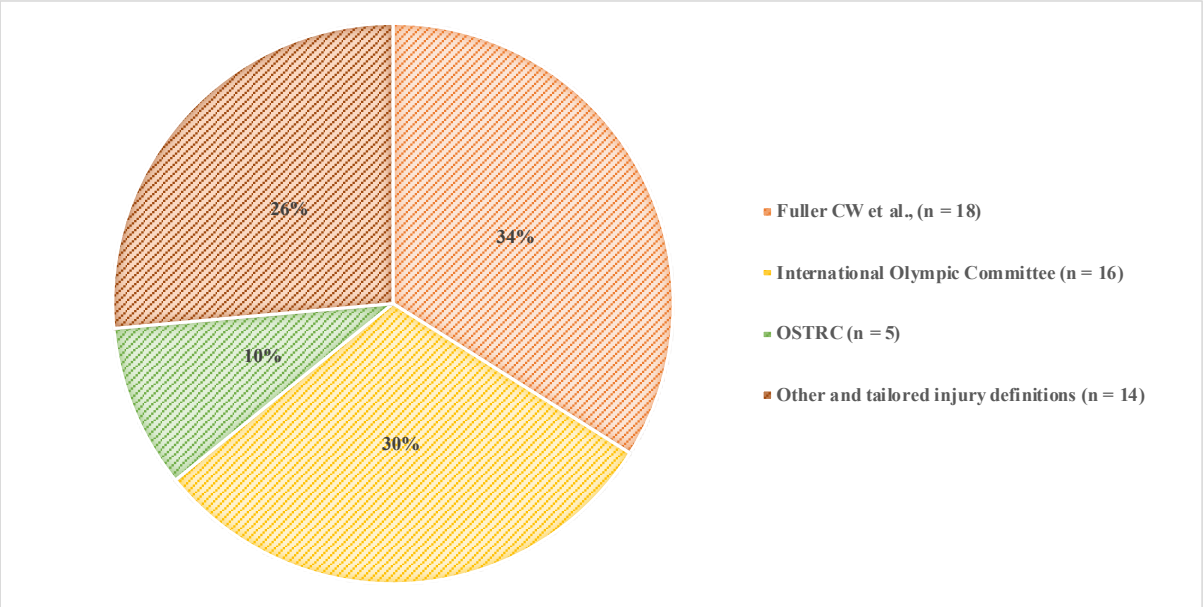


**Fig 2** Injury definitions used in the included studies in stage 1 of the TRIPP framework. *OSTRC: Oslo Sports Trauma Research Centre*

**Supplementary information 5: TRIPP Stage 2 – Establishing the etiology and mechanisms of injury**

**Table 1** Data extraction of the included studies in stage 2 of the TRIPP framework. *ACL: anterior cruciate ligament; ACL-R: anterior cruciate ligament reconstruction; AI: asymmetry index; CG: control group; CMJ: countermovement jump; DBB: deadbug bridging exercise; DH: downhill; DPSI: dynamic postural stability index; EC: European Cup; F: female/s; FIS: International Ski and Snowboarding Federation; GRF: ground reaction force; GS: giant slalom; IG: intervention group; ISS: Injury Surveillance System; LSI: limb symmetry index; M: male/s; MRI: magnetic resonance imaging; OSTRC: Oslo Sports Trauma Research Centre; SBRS: ski boot rear stiffness; SG: Super-G; SJ: squat jump; SL: slalom; SSC: stretch-shorten-cycle; SSPT: Swiss Ski Power Test; WC: World Cup; WOG: Winter Olympic Games.*

| **Study features** | **Aim of the study** | **Sample characteristics** | **Study context** | **Injury data** | **Injury etiology** |
|---|---|---|---|---|---|
| **Author, year, study design, country/federation** | | **a) Sample size (n)**<br>**b) Gender**<br>**c) Age** | **a) Competition level (alpine skiing discipline)**<br>**b) Time of the season/year** | **a) Injury definition**<br>**b) Injury reporting method** | **Injury mechanisms and/or inciting events** |
| Abrahamson J et al., 2020[40]<br>Prospective cohort study<br>Sweden | to investigate the correlation between the presence and the size of cam morphology, hip pain, and activity level at a minimum of 5 years follow-up, in a cohort of young elite skiers. | a) n=60<br>b) F30, M30 (elite: F6, M10)<br>c) 23.6 ± 1.1 | a) Youth level<br>b) Winter season | | |
| Alhammoud M et al., 2022[41]<br>Pilot study<br>France | to examine the impact of repeated ski runs on electromyographic activity (EMG) of the knee extensors and flexors in elite alpine skiers, by characterising on-field neuromuscular adjustments and EMG variability in elite skiers repeating four high-intensity runs. | a) n=19<br>b) F8, M11<br>c) F23 ± 2, M24 ± 5 | a) WC- and EC-levels (all disciplines)<br>b) Winter in southern hemisphere | | |

| | | | | | |
|---|---|---|---|---|---|
| Alhammoud M et al., 2020[42]<br>Prospective cohort study<br>France | to investigate the joint kinematic characteristics of elite alpine skiers according to leg and discipline. | a) n=20 (WC n=13, EC n=7)<br>b) F9, M11<br>c) F23.0 ± 2.0; M24.0 ± 5.0 | a) WC-level and EC-level (all disciplines: SL/GS n=15; SG/DH n=5)<br>b) Two summer season (winter seasons in southern hemisphere: Argentina) | | |
| Alhammoud M et al., 2019[43]<br>Experimental field study<br>France | to explore a novel isokinetic analysis approach throughout the range of motion based on statistical parametric mapping; and to determine the influence of sex and discipline on torque and hamstrings-quadriceps ratio in elite alpine skiers. | a) n=28<br>b) F14, M14<br>c) F21.2 ± 3.0; M23.0 ± 3.8 | a) WC-level and EC-level (all disciplines)<br>b) Preseason | | |
| Bere T et al., 2011[14]<br>Case series | to describe the skiing situation leading to ACL injuries in the WC alpine skiing based on a technical analysis of the video recordings. | a) n=20 (n=14 experts) | a) WC-level (all disciplines): Current WC coaches (n=10), former WC coaches (n=3), current national team's coaches, and recently retired WC ski racer (n=1)<br>b) Winter season | | ACL: (1) "Slip-catch", (2) "dynamic snowplough", (3) "landing back-weighted". |
| Bere T et al., 2011[22]<br>Case series | to describe the injury situations and mechanisms of ACL injuries among WC alpine skiers based on systematic analysis of video recordings. | a) n=20 (n=7 experts)<br>b) F7, M13 | a) WC-level (all disciplines). Skiing biomechanists (n=4), and orthopaedic surgeons (n=3)<br>b) Winter season | | ACL: (1) "Slip-catch", (2) "dynamic snowplough", (3) "landing back-weighted". |
| Bere T et al., 2014[10]<br>Case series | to describe the injury situations in WC alpine skiing based on systematic video analysis of real injury situations. | a) n=69<br>b) F24, M45 | a) WC-level<br>b) Winter season | | Turning or landing from a jump. |

| | | | | | |
|---|---|---|---|---|---|
| Bere T et al., 2013[53]<br>Case series | to examine the detailed time course of knee and hip kinematics of 2 typical slip-catch situations in World Cup alpine skiing reported through the International Ski Federation (FIS) Injury Surveillance System. | a) n=2<br>b) F1, M1<br>c) 27.5 ± 1.5 | a) WC-level (SL)<br>b) Winter season | | "Slip-catch" |
| Bergeron MF et al., 2012[54]<br>Consensus | to highlight selected key environment-related risk factors that continue to challenge Olympic and other international-level athletes; and to re-emphasise and provide additional recommendations to address and minimise those risks associated with recent and ongoing incidents of environmentally prompted illness, injury and death in sport. | | | | |
| Bruhin B et al., 2020[58]<br>Pilot study<br>Switzerland | to identify differences in sections of the runs (course setting, steepness) and performance parameters (e.g., speed, time per turn, turn phases etc.) among young and older athletes. | a) n=57 (elite n=7; U21 n=11; U18 n=13; U16 n=6; U14 n=13; U12 n=7)<br>b) M<br>c) Elite >21 (born 1992±2.18) | a) Elite level, U21, U18, U16, U14, U12 (GS)<br>b) Multiple winter seasons | | |

| | | | | | |
|---|---|---|---|---|---|
| Carraro A et al., 2020[59]<br>Cross-sectional study<br>Italy | to describe the demographics, sports exposure, and other sports- or warm-up-related practices of adolescent competitive alpine skiers; to assess the prevalence of lower back complaints in this specific cohort with respect to sex, category, and discipline preference; to explore their lower back complaints severity (i.e., intensity and disability); and to investigate the potential relations with training attributes. | a) n=188 (U16 n=128; U18 n=60)<br>b) F78, M110<br>c) F: 16.0 ± 1.0; M: 16.1 ± 1.1 | a) U16, U18<br>b) End of competitive season | a) Other and tailored definitions[59]<br>b) Tailored questionnaire forms[59] | |
| Crestani L et al., 2014[61]<br>Retrospective cohort study<br>France | to comprehend the ACL risk factors in the elite skiers between 2002 and 2010. | a) n=42<br>b) F24, M18<br>c) Range F: 16-28; M: 23-32 | a) Elite level and WOG event<br>b) Season: in- and off-season | b) Online questionnaire (French National team)[61] | |
| Csapo R et al., 2021[64]<br>Retrospective cohort study | to analyse the effects of graft selection, sex, injury complexity and time to return to competition on the odds to suffer secondary ACL injury (either re-rupture or contralateral ACL tear) in professional alpine skiers. | a) n=30<br>b) F17, M13<br>c) 21.6 ± 4.0 | a) FIS competitions level, EC-level and WC-level | | |
| Eberle R et al., 2017[66]<br>Experimental lab study | to analyse the effect of different SBRS on the maximal ACL tensile force during injury prone landing movements in alpine ski racing using the musculoskeletal simulation model of Heinrich et al. (2014) with an improved ski boot model. | | | | |
| Eberle R et al., 2019[67]<br>Experimental laboratory study | to develop a planar multibody simulation model of a mono-skier and investigate transversal vibrations of unedged skis during schussing in the fall line over rough (random) ski slopes. | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Ellenberger L et al., 2021[68]<br>Experimental field study<br>Switzerland | to evaluate the reliability of quantifying thigh muscle activation patterns and dynamic knee valgus at peak ground reaction force during DJ landings; to provide reference values for female and male youth competitive alpine skiers; and to study their associations with age, anthropometrics, biological maturation and the occurrence of knee overuse complaints. | a) n=144<br>b) F47, M67<br>c) F: 14.7 ± 0.6; M: 14.9 ± 0.5 | a) U16 | a) Other and tailored definitions[68]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | |
| Ellenberger L et al., 2020[69]<br>Cross-sectional and experimental field study<br>Switzerland | to introduce a novel biomechanical approach for quantifying athletes' rear chain stabilisation performance during DBB and to assess its test-retest reliability; to describe DBB performance in two distinct populations (i.e., female and male competitive alpine skiers of the U16 category and competitive alpine skiers of the elite category) with respect to sex; and to investigate the association between DBB performance, age, anthropometrics, biological maturation, skiing performance and the occurrence of back overuse complaints in U16 skiers undergoing phases of rapid musculoskeletal growth. | a) n=171 (U16 n=133; elite n=38)<br>b) U16: F49, M84; elite: F19, M19 | a) U16 and elite level | b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | |
| Fitze DP et al., 2022[73]<br>Prospective cohort study<br>Switzerland | to provide reference values regarding lumbar multifidus morphology of female and male youth competitive alpine skiers; to investigate the influence of biological maturation on lumbar multifidus morphology; to verify whether lumbar multifidus morphology is associated with DBB performance; and to compare the lumbar multifidus morphology of symptomatic and asymptomatic skiers and examine the potential clinical relevance of these findings. | a) n=85 (U16 n=45, U15 n=40)<br>b) F28, M57<br>c) F14.7 ± 0.7, M14.9 ± 0.5 | a) U16, U15 (youth level)<br>b) One year | a) Other and tailored definitions: overuse-related back complaints[73]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | |
| Fröhlich S et al., 2020[77]<br>Prospective cohort study<br>Switzerland | to prospectively investigate the prevalence and severity of knee-related, back-related and hip-related overuse injuries in top female elite alpine skiers during the off-season preparation period; and to assess the relationship of knee complaints with traumatic preinjuries and the total training hours. | a) n=26 (SL-GS n=15; SG-DH n=11)<br>b) F<br>c) 20.91 ± 2.67 | a) Elite athletes (all disciplines)<br>b) Off-season | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | |

| | | | | | |
|---|---|---|---|---|---|
| Gilgien M et al., 2015[83,84]<br>Cross-sectional study | to characterise course setting, terrain geomorphology and their relationship to speed in male WC giant slalom, super-G and downhill. | a) n=14<br>b) M | a) WC-level (GS, SG, DH)<br>b) Multiple winter seasons | | |
| Gilgien M et al., 2018[85]<br>Cross-sectional study | to capture the external forces acting on forerunners skiing World Cup races in GS, SG and DH. | b) M<br>c) 25.1 ± 3.5 | a) Forerunners: former male WC-level or current EC-level (GS, SG and DH)<br>b) Winter season | | |
| Gilgien M et al., 2014[24]<br>Case series | to quantify these important skiing-related variables for the disciplines GS, SG and DH. We also investigated whether these variables could explain the differences in the number of injuries per 1000 runs among the disciplines. | a) n=34 | a) Former WC or current EC racer (GS, SG, DH)<br>b) Multiple winter seasons | | |
| Gong T et al., 2022[87]<br>Experimental lab study | to develop an improved simulation method based on inverse dynamics and to assess the effects of improper skiing motions on ACL injuries. | | | | |
| Hanimann J et al., 2023[91]<br>Cross-sectional study<br>Switzerland | to determine whether there are distinct differences in leg axis and core stability between soccer players and skiers; to investigate whether youth soccer players and alpine skiers exhibit leg axis and core stability differences between the dominant and non-dominant sides; and to explore the outcomes of applying common sport-specific asymmetry thresholds to these two distinct cohorts. | a) n=61<br>c) 15.7 ± 0.1 | a) Youth level<br>b) Prior competition season | | |

| | | | | | |
|---|---|---|---|---|---|
| Heinrich D et al., 2014[92]<br>Experimental lab study | to develop a musculoskeletal modelling and simulation approach to investigate the effect of a perturbed landing position, i.e., joint angles and trunk orientation, on peak ACL force during the subsequent landing movement. | | | | |
| Heinrich D et al., 2018[93]<br>Experimental lab study | to quantify the effect of landing height on peak ACL force during jump landing in downhill skiing, and to compare the effects of landing height and landing position. The landing position was represented by the trunk lean of the skier. | | a) (DH) | | |
| Heinrich D et al., 2022[94]<br>Experimental lab study | to develop a three-dimensional musculoskeletal model of an alpine skier capable of simulating turning manoeuvres; and to apply the musculoskeletal skier model in combination with a forward dynamics optimization framework to estimate dynamically consistent kinematics, ground reaction forces and joint moments during a turning manoeuvre. | | | | |
| Hildebrandt C et al., 2017[95]<br>Case-control study<br>Austria | to compare trunk strength capacities and flexion/extension core ratios in elite alpine skiers with a matched control group according to gender. | a) n=109 (WC n=23, EC n=43, Junior n=44)<br>b) F56, M53<br>c) F: 22.4 ± 3.4; M: 22.1 ± 3.6 | a) WC-level, EC-level and Junior<br>b) Precompetitive season | | |
| Ineichen J et al., 2021[100]<br>Cross-sectional study (descriptive)<br>Switzerland *(n=86)*, United States of America and Austria *(n=75)* | to analyse the type and incidence of dental injuries among professional FIS-ranked skiers in relation to their alpine skiing discipline (speed vs. technical), performance level, and years of experience. | a) n=190 (WC n=5; EC n=40; FIS competitions n=113)<br>b) M | a) WC-level, EC-level, FIS-competitions level<br>b) Multiple seasons | | |

| | | | | | |
|---|---|---|---|---|---|
| Javet M et al., 2022[103]<br>Cross-sectional study<br>Switzerland | to explore reasonable application purposes and potential confounders of the SSPT in youth competitive alpine skiers. | a) N=144 (U16 n=31, U15 n=81, U14 n=32)<br>b) F57, M87 (F: U16 n=9, U15 n=34, U14 n=14; M: U16 n=22, U15 n=47, U14 n=18)<br>c) 14.5 (14.3–14.6) | a) U16, U15, U14<br>b) Prior competition season | a) Fuller CW et al., definitions[45,46]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | |
| Jordan MJ et al., 2014[105]<br>Cross-sectional study<br>Canada | to quantify bilateral lower limb functional asymmetry using the CMJ and SJ phase-specific kinetic impulse asymmetry index (AI) in uninjured and ACL-R elite ski racers and asymmetry in lower limb muscle mass measured with dual X-ray absorptiometry (DXA) scanning. | a) n=18 (IG n=9; CG n=9)<br>b) F9, M9<br>c) 24.55 ± 2.39 | a) WC-level<br>b) Start off-season | | |
| Jordan MJ et al., 2015[106]<br>Case-control study<br>Canada | to perform a comprehensive hamstrings and quadriceps muscle strength assessment and to evaluate lower limb muscle mass in a group of actively competing elite alpine ski racers with/without ACL-R. | a) n=21 (n=8)<br>b) F8, M13<br>c) 22.55 ± 2.8 | a) WC-level<br>b) Start off-season | | |
| Jordan MJ et al., 2016[107]<br>Cross-sectional study<br>Canada | to assess the effects of acute neuromuscular fatigue on vertical jump performance, bilateral functional asymmetry, and quadriceps/hamstring muscle activity in elite alpine ski racers with/without ACLR. | a) n=22<br>b) F10, M12<br>c) F: 23.6 ± 1.8; M: 26.5 ± 5.8 | a) WC-level<br>b) Prior competition season | | |
| Jordan MJ et al., 2022[109]<br>Case-control study<br>Canada | to evaluate by a nonlinear analysis the time-course change in SSC capacity in non-injured female alpine ski racers between 16 and 32 years of age; to evaluate the recovery of SSC function after ACL injury and ACLR that included recovery of the eccentric deceleration and concentric kinetic impulse, respectively, as manifested by temporal change in absolute SSC function and the between-limb kinetic impulse AI. | a) n=32<br>b) F<br>c) Range 16-32 | a) Elite level | | |

| | | | | | |
|---|---|---|---|---|---|
| Kiers K et al., 2022[112]<br>Prospective cohort and test-retest study<br>Switzerland | to study the test-retest reliability of DPSI assessments using a ski-specific jump protocol that consists of single-leg landings on a three-dimensional force plate after forward-performed double-leg drop jumps from a box over a hurdle (DJSLLs); to provide reference values for female and male youth competitive alpine skiers; to explore their changes in DPSI over 3 years during adolescence; and to investigate potential associations of DPSI with age and biological maturation. | a) n=76<br>b) F30, M46<br>c) 13.7 ± 0.6 | a) U16<br>b) Prior competition season | | |
| Mildner E et al., 2010[118]<br>Cross-sectional study<br>Austria | to analyse the influence of ski boots on balance performance of alpine skiers. | a) n=76<br>b) F33, M43<br>c) Students (F 23.8±1.6, M 24.9±2.6); Skiers (F 16.9±1.1, M 16.8±1.1) | a) Youth level<br>b) Prior competition season | | |
| Mössner M et al., 2009[119]<br>Experimental lab study | to investigate the influence of ski stiffness on the trajectory of the skier performing a sequence of turns. | | | | |
| Muller L et al., 2017[122]<br>Prospective cohort study<br>Austria | to investigate intrinsic risk factors for injuries such as anthropometrics, biological maturity status, physical fitness and ski racing technique among youth ski racers younger than 15 years of age. | a) n=81<br>b) F31, M50<br>c) 11.6 ± 1.4 | a) Junior level<br>b) Multiple school years | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] | |

| | | | | | |
|---|---|---|---|---|---|
| O'Neill DF 2008[124]<br>Qualitative study<br>United States of America | to evaluate whether non-injured peers of athletes who experience an ACL injury exhibit higher levels of negative affect and emotions than athletes who do not have an injured teammate; and whether athletes with injured teammates are at higher risk for injury than those without injured teammates. | a) n=459<br>b) F182, M277<br>c) Range 13-19 | a) Youth level | | |
| Ogrin J et al., 2021[125]<br>Experimental field study | to determine whether asymmetries in basic muscular strength are related to the GRFs encountered during elite slalom skiing. | a) n=9<br>b) M<br>c) 22.7 ± 3.4 | a) EC-level (SL)<br>b) Winter season | | |
| Peterhans L et al., 2020[129]<br>Cross-sectional study<br>Switzerland | to describe the prevalence of overuse-related MRI findings in the lumbar spine of youth competitive alpine skiers of the under 16-years (U16) category with respect to sex- and sex-specific differences in height growth; to assess the associations between MRI findings and biological maturation-dependent multifidus size; to investigate the relationship of MRI findings with age; and to compare the MRI findings of asymptomatic and symptomatic athletes and to explore their clinical relevance. | a) n=108<br>b) F42, M66<br>c) 14.83 ± 0.58 | a) U16<br>b) Season: in- and off-season | a) OSTRC definitions[49,50]; Other and tailored definitions[129]<br>b) OSTRC questionnaire on health problems[49,50] | |
| Raschner C et al., 2012[134]<br>Retrospective cohort study<br>Austria | to determine the relationship between ACL injuries and internal risk factors. | a) n=370<br>b) F175, M195<br>c) Range 14-19 | a) Youth level<br>b) Multiple seasons | | |
| Schindelwig K et al., 2014[138]<br>Experimental field study | the development of a simulation model to predict the injury hazard of jumps in downhill ski races. | | a) WC-level<br>b) Winter season | | |

| | | | | | |
|---|---|---|---|---|---|
| Schmitt KU et al., 2016[139]<br>Retrospective cohort study (using historical data)<br>Switzerland | to investigate retrospectively whether physical fitness is associated with knee injury history, especially ACL rupture. | a) n=70<br>b) F38, M32<br>c) 15.1 ± 2.1 | a) Elite athletes (all disciplines) | | |
| Schoeb T et al., 2020[141]<br>Prospective cohort study<br>Switzerland | to investigate the prevalence of the health problems typically occurring in youth competitive alpine skiers by the use of the OSTRC questionnaire and with respect to sex, chronological age, and season differences; to describe their duration, severity, and location; and to assess the relationship between biological maturation and the occurrence and severity of health problems. | a) n=155 (U15 n=77; U14 n=78)<br>b) F59, M96<br>c) 13.89 ± 0.60 | a) U15, U14<br>b) Season: in- and off-season | a) OSTRC definitions[49,50]<br>b) OSTRC questionnaire on health problems (and retrospective interviews)[49,50] | |
| Spiess J et al., 2019[143]<br>Case-control study<br>Switzerland | to establish whether the hamstrings of alpine ski racers show eccentric strength deficits following surgery on the anterior cruciate ligament. | a) n=88 (70+18)<br>b) F40, M48 - F29, M41 - F11, M7<br>c) 19.72 ± 3.35 | a) Elite level<br>b) Precompetitive season | | |
| Spörri J et al., 2010[144]<br>Qualitative study | to generate, together with the other ISS projects, a comprehensive discussion basis for short term regimens in terms of specific risk factors and mechanisms behind injuries. | a) n= 63:<br>athletes (n=12), coaches (n=19), officials/race organisers (n=12), representatives ski equipment companies (n=10), topic specific experts (n=10) | a) WC-level<br>b) Winter season | | |

| | | | | | |
|---|---|---|---|---|---|
| Spörri J et al., 2012[13]<br>Qualitative study | to compile a list of perceived intrinsic and extrinsic risk factors for severe injuries in alpine WC ski racing; and to derive precise qualitative statements about those factors that are thought to have the highest impact on injury risk in order to provide more detailed hypotheses for further studies. | a) n= 61:<br>Athletes (allrounders n=7, speed n=3, technical n=1), Coaches (n=30), Officials/race organisers (n=11), representatives ski equipment companies (n=10), topic specific experts (n=10) | a) WC-level (all disciplines)<br>b) Winter season | | |
| Spörri J et al., 2016[145]<br>Experimental field study | to investigate the effect of increased gate offsets on the biomechanical variables related to spinal disc loading in GS and SL; and to compare the aforementioned variables between these competition disciplines. | a) n=10 | a) WC-level and EC-level (GS and SL)<br>b) Winter season | | |
| Spörri J et al., 2017[147]<br>Experimental field study | to describe power spectral density (i.e., the signal's power distribution over frequency) of the vibrations acting on the different body segments in the competition disciplines GS and SL; and to quantify and compare the root-mean square (RMS) accelerations acting on the lower back (i.e., the severity of vibration exposure) while skiing GS and SL turns. | a) n=6<br>b) M | a) EC-level (GS and SL)<br>b) Winter season | | |
| Spörri Jet al., (2016)[148]<br>Experimental field study | to investigate the effect of skis with different sidecut radii on variables related to the mechanics of turning in GS; and to discuss the findings in the context of injury prevention in alpine ski racing. | a) n=6 | a) EC-level (GS)<br>b) Winter season | | |

| | | | | | |
|---|---|---|---|---|---|
| Spörri J et al., 2015[149]<br>Experimental field study | to describe the sport-specific, overall trunk kinematics and skiers' loading during giant slalom (GS) turns; to investigate the general potential to affect the aforementioned factors by external preventive measures, such as the recent changes in the equipment rules of the International Ski Federation (FIS) by comparing "old" GS skis versus "newly regimented" GS skis (longer skis with less width and less sidecut). | a) n=8 | a) EC-level (GS)<br>b) Multiple winter seasons | | |
| Spörri J et al., 2012[150]<br>Experimental field study | to investigate the effect of increased horizontal gate distance on energy-related and injury mechanism-related variables in GS. | a) n=1 | a) WC-level (GS) | | |
| Spörri J et al., 2019[151]<br>Editorial | | | | | |
| Spörri J et al., 2022[152]<br>Experimental field study | to biomechanically describe the corresponding ACL injury case from a functional perspective and in comparison to "normal" reference skiing. | a) n=1<br>b) M<br>c) 30 | a) EC-level (GS)<br>b) Winter season | | "Slipping edge-catch" |
| St-Onge N et al., 2004[154]<br>Experimental lab study | to evaluate the effect of the position of the pivot point on ACL strain and thus on the chances of tearing the ligament; and to evaluate the effect of binding release characteristics on ACL strain. | | | | |
| Steenstrup SE et al., 2017[156]<br>Case series | to analyse head and face injuries recorded by the FIS Injury Surveillance System (ISS) through 10 seasons (2006–2016) of WC alpine and freestyle skiing and snowboarding to describe their mechanisms. | a) n=29<br>c) 27.0 ± 5.7 | a) WC-level and WOG event (DH, SG, GS, SL)<br>b) Winter season | a) Fuller CW et al., definitions[45,46]; Other and tailored definitions[156] | Head and face: After turning or landing after a jump. Ski racers rolling, yawing and/or pitching. |

| | | | | | |
|---|---|---|---|---|---|
| Steenstrup SE et al., 2017[158]<br>Case series | to describe the injury mechanisms in a selection of head impact injury cases meeting our inclusion criteria among WC alpine skiers; to describe the gross head impact biomechanics; and to compare the head impact kinematics with relevant helmet standards. | a) n=7<br>b) F3, M4 | a) WC-level and WOG event (DH and SG)<br>b) Winter season | | Head: ski racers pitching backwards (1-2) or pitching forward or backwards in a spiralling motion (3). |
| Steidl-Müller L et al., 2018 - study 1[160]<br>Cross-sectional study<br>Austria | to assess the influence of age-related performance levels on the LSI in high-level, competitive, non-injured athletes to assess the natural range of LSI. | a) n=285 (Youth n=95; Adolescent n=107; Elite n=83)<br>b) Youth: F39, M56; Adolescent: F47, M60; Elite: F39, M44<br>c) Youth: 11.9 ± 1.1; Adolescent: 16.3 ± 1.4; Elite: 21.5 ± 3.1 | a) Youth level (youth and adolescent), elite level (WC-, EC-, FIS competitions levels)<br>b) Prior competition season | | |
| Steidl-Müller L et al., 2018 - study 2[160]<br>Prospective cohort study<br>Austria | to prospectively assess limb differences as a possible risk factor for traumatic and overuse injury in youth ski racers. | a) n=67<br>b) F25, M43<br>c) F: 12.3 ± 1.1; M: 12.0 ± 1.2 | a) Youth level<br>b) Multiple seasons | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) IOC injury surveillance system for multisport events[52] | |
| Steidl-Müller L, Hildebrandt C, Müller E, et al (2020)[161]<br>Prospective cohort study<br>Austria | to investigate prospectively the role of biological maturity status, and changes in anthropometric characteristics, as well as changes in physical fitness parameters over one season in the context of injury risk identification in elite youth ski racers younger than 15 years of age. | a) n=89<br>b) F39, M50<br>c) 12.1 ± 1.3 | a) Youth level<br>b) Winter season | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]<br>b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] | |

| | | | | | |
|---|---|---|---|---|---|
| Steidl-Müller L et al., 2020[162]<br>Prospective cohort study<br>Austria | to investigate prospectively over a period of 4 seasons the role of biological maturity status, body weight, and body height percentiles and core flexion to extension strength ratios in the context of traumatic and overuse injury risk identification in elite youth ski racers from the ages of 10 years at the beginning of the observation period. | a) n=72<br>b) F27, M45<br>c) 10.6 ± 0.3 (Range 10-14) | a) Youth level<br>b) Season: in- and off-season | a) OSTRC definitions[49,50]; Fuller CW et al., definitions[45,46]; IOC consensus statement definitions[52]<br>b) Online questionnaire (Austrian Ski Team) - Internet-based database[2] | |
| Supej M et al., 2015[166]<br>Cross-sectional study | to determine the influence of the steepness of the slope on kinematic and kinetic variables during a slalom ski race. | a) n=10<br>b) M<br>c) 26.9 ± 2.5 | a) WC-level (SL)<br>b) Winter season | | |
| Supej M et al., 2019[167]<br>Commentary | to provide an update on the biomechanics of alpine ski racers and their equipment. | | a) WOG event (all disciplines)<br>b) Winter season | | |
| Supej M et al., 2018[168]<br>Experimental field study | to examine whole-body vibrations connected with different types of skiing and the associated potential risk of developing low back pain. | a) n=8 | a) Former competitive level (SL)<br>b) Winter season | | |
| Tecklenburg K et al., 2007[170]<br>Case report study | to describe first case of an acute anterior cruciate ligament deficiency combined with simultaneous locked bucket-handle tears of both medial and lateral menisci in an athlete including injury mechanism, clinical symptoms, specific signs on MRI, and treatment options. | a) n=1<br>b) F<br>c) 19 | a) (DH)<br>b) Winter season | | |

| | | | | | |
|---|---|---|---|---|---|
| Tudor A et al., 2003[172]<br>Case report study<br>Croatia | to explore the mechanisms of intra-articular calcaneal fractures in young competing skiers, as well as to emphasise the possibility of an unusual and severe foot injury despite the use of sophisticated ski equipment and excellent physical fitness. | a) n=1<br>b) M<br>c) 14 | a) Youth level (GS)<br>b) Winter season | | |
| Westin M et al., 2018[177]<br>Case-control study<br>Sweden | to study potential intrinsic and extrinsic risk factors for ACL injuries in competitive adolescent alpine skiers between 16 and 20 years of age. | a) n=339<br>b) F163, M176<br>c) ACL: 17.6 ± 1.1; Non-ACL: 17.7 ± 1.2 | a) Youth level<br>b) Multiple seasons | | |
| Westin M et al., 2022[179]<br>Prospective cohort study<br>Sweden | to investigate possible intrinsic risk factors for an ACL reinjury in young competitive alpine skiers during their ski high school years; and to describe this sub-cohort of students from a health perspective using the RAND 36-Item health survey 1.0. | a) n=384 (n=31)<br>b) F193, M191 (F26, M5)<br>c) 16.5 ± 0.5 | a) Youth level<br>b) Prior competition season | a) Other and tailored definitions[179]<br>b) Tailored questionnaire forms[179] | |
| Westin M et al., 2016[181]<br>Cross-sectional study (descriptive)<br>Sweden | to investigate whether there is any relationship between the prevalence of ACL injuries in alpine ski students at elite level and ACL injuries in their parents. | a) n=593<br>b) F293, M300<br>c) 20.5 ± 2.6 | a) Youth level | | |
| Wolfsperger F et al., 2015[183]<br>Cross-sectional (descriptive), experimental field and lab study | to quantify snow conditions and their spatial and temporal variation within each monitored track as well as to detect differences between the seven analysed WC races. | a) n=3 observers, n=50 athletes | a) WC-level (DH, GS)<br>b) Winter season | | |

| | | | | | |
|---|---|---|---|---|---|
| Yamazaki J et al., 2015[184]<br>Case series | to estimate head impact velocities in a crash at a World Cup downhill skiing event that resulted in the athlete suffering a severe TBI, using a model-based image matching (MBIM) technique; and to demonstrate the utility of this method for future implementation in a cohort study of ski crash incidents. | a) n=1<br>b) M<br>c) 30 | a) WC-level (DH)<br>b) Winter season | | |
| Zorko M et al., 2015[185]<br>Experimental field study<br>Slovenia | to establish how the knee-joint kinematics changes during a skiing turn, using skis with different waist widths. | a) n=6<br>c) 23.33 ± 3.44 | a) Youth and former competitors (course similar to GS)<br>b) Winter season | | |

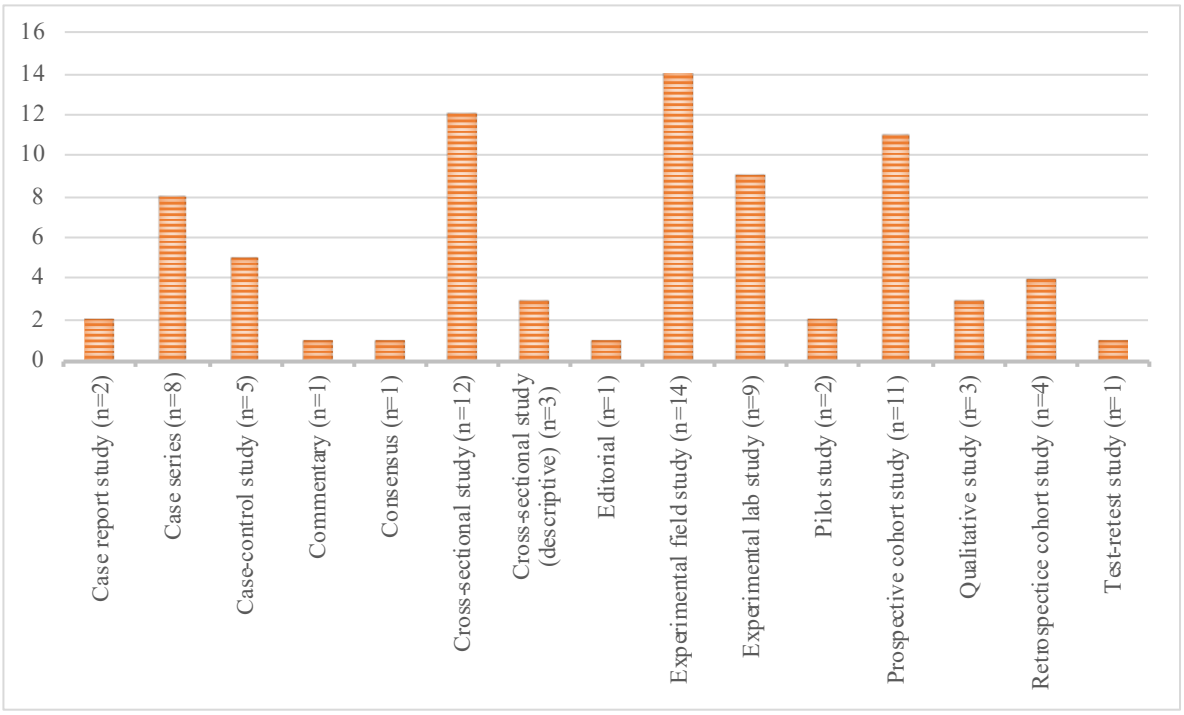


**Fig 1** Study designs of the included studies in stage 2 of the TRIPP framework.

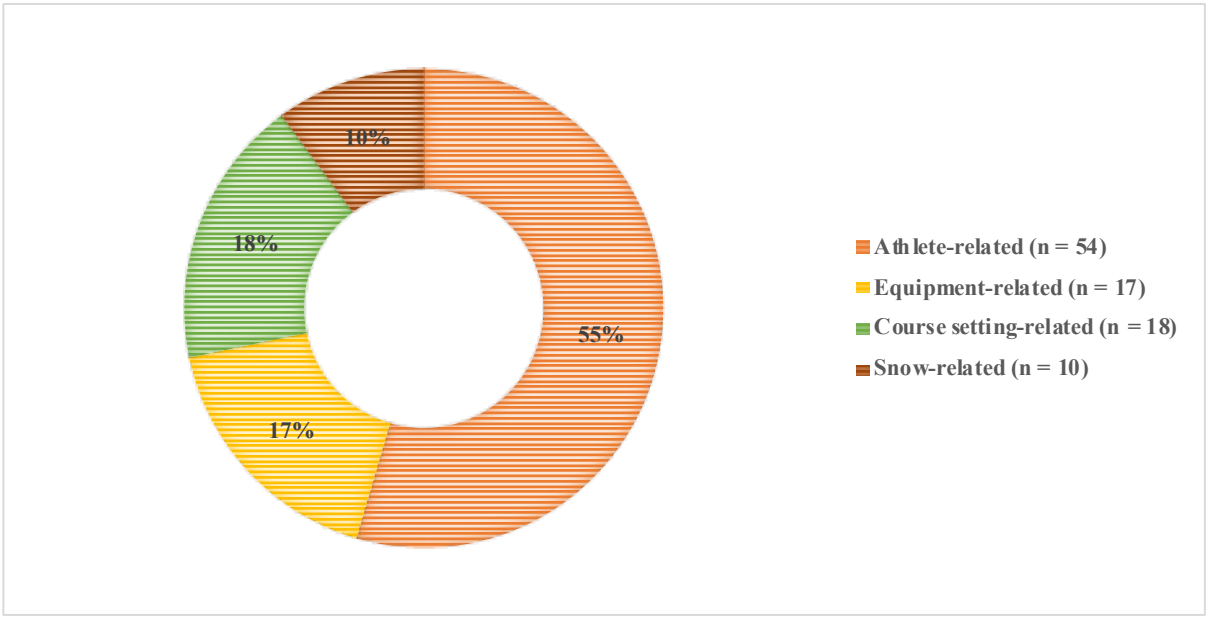


**Fig 2** Related factors of the included studies in the second stage of the Translating Research into Injury Prevention Practice (TRIPP) framework.

**Table 2** Injury risk factor classification based on risk factor rating. *Classification adapted from Kiers et al.*[29]

| # | Risk factor rating | Risk-related factor | Examples |
|---|---|---|---|
| **1** | Changing snow conditions[13,14,144] | Snow | |
| **2** | System ski, plate, binding, boot[13,144,167] | Equipment | Heavy equipment weight |
| **3** | Fatigue[13,59,144,179] | Athlete | Within a course or training session, and due to schedule/jetlag |
| **4** | Course maintenance during race[13,144] | Course setting | |
| **5** | Physical aspects[1,10,13,42,44,68,69,73,77,91,95,103,105–107,109,112,115,122,125,129,134,143,144,160–162,166,167,177,179] | Athlete | Insufficient physical fitness, insufficient core strength/core strength imbalances |
| **5** | Aggressive snow conditions[13,14,22,144] | Snow | |
| **5** | Bad visibility[13,144] | Course setting | Poor visibility |
| **8** | Smooth or too bumpy snow surface [13,14,22,144] | Snow | |
| **9** | Techniques of snow preparation[13,14,61,85,144] | Snow | Water-injected/noninjected snow |
| **10** | Athlete's race preparation [13,59,77,144] | Athlete | |
| **10** | Athlete's crash behaviour[13,22,50,144,152,156] | Athlete | Adverse behaviour |
| **12** | Speed and course setting aspects[13,83,84,144,166,167] | Course setting | High skiing speed combined with terrain transitions |
| **13** | Skiing technique and tactics[1,10,13,14,22,53,69,87,92,93,100,103,122,139,144,152,156,167,168] | Athlete | High skill level, technical mistakes, inappropriate tactical choices |
| **14** | Course setting in general[13,24,83,84,144,145,167] | Course setting | High skiing speed combined with small turn radii |
| **14** | Athlete's individual responsibility[13,61,144,152,156] | Athlete | Poor responsibility, risk management |
| **16** | Psychological aspects [13,124,144] | Athlete | Poor mental skills |
| **16** | Protectors and helmets[10,13,144,156,167,184] | Equipment | Insufficient body and head protection |
| **18** | Binding/plate[13,22,61,144,154,167] | Equipment | Non-release/inadvertent release of bindings |

| | | | |
|---|---|---|---|
| **19** | Skis[13,119,144,148,149,167,185] | Equipment | Skis with high torsional stiffness/homogenous bending lines; highly-shaped, short and wide skis |
| **19** | Athlete's adaptability[13,59,144,156] | Athlete | Insufficient adaptability |
| **21** | Preinjury aspects [13,64,77,105,106,109,124,144] | Athlete | |
| **22** | Racing suits[13,144,167] | Equipment | Insufficient body protection |
| **22** | Speed and topographic aspects[13,83,84,144] | Course setting | High skiing speed combined with terrain transitions |
| **24** | Jumps[10,13,24,93,138,144] | Course setting | Inappropriate jump construction |
| **24** | Level of course difficulty [13,58,144] | Course setting | |
| **26** | Genetics, anthropometry, age and sex[1,13,68,69,73,103,112,122,129,134,141,144,162,181] | Athlete | Unfavourable genetic predisposition and anthropometrics, female and male sex |
| **27** | Speed in general[13,85,144,167] | Course setting | High speeds |
| **28** | Gates (panels and poles)[10,13,144] | Equipment | Gates with high resistance |
| **29** | Safety net position and spill zone[13,144] | Course setting | Inappropriate net positions and limited spill zones |
| **30** | Topography in general [13,67,83,84,144,166] | Course setting | |
| **31** | Aspects of body temperature[13,54,144] | Athlete | Low peripheral body temperature |
| **31** | Ski boots[13,66,118,144] | Equipment | Stiff boots |

**Table 3** Perceived stakeholders' injury risk factor rating by competition level and stakeholders' active roles. *Adapted from Kiers et al.*[29] *FIS: International Ski and Snowboarding Federation.*

| Rank and context setting | Perceived injury risk factor category |
|---|---|
| World Cup-level | |
| **1** | Changing snow conditions |
| **2** | System ski, plate, binding, boot |
| **3** | Aggressive snow conditions |
| European Cup-level | |
| **1** | Fatigue |
| **2** | Changing snow conditions |
| **3** | Physical aspects; and bad visibility |
| FIS competitions-level | |
| **1** | Changing snow conditions |
| **2** | Physical aspects |
| **3** | Course maintenance during race |
| Athletes | |
| **1** | Changing snow conditions |
| **2** | Course maintenance during race |
| **3** | System ski, plate, binding, boot; and bad visibility |
| Coaches | |
| **1** | Changing snow conditions |
| **2** | Fatigue |
| **3** | Aggressive snow conditions |
| Team medical staff | |
| **1** | Fatigue |
| **2** | Physical aspects |
| **3** | Changing snow conditions |
| Ski racing supplier representatives | |
| **1** | Changing snow conditions |
| **2** | System ski, plate, binding, boot |
| **3** | Techniques of snow preparation |
| FIS representatives | |

| | |
|---|---|
| **1** | Athletes' individual responsibility |
| **2** | System ski, plate, binding, boot |
| **3** | Athlete's race preparation; fatigue; speed and course setting aspects; and smooth snow surface |

**Supplementary information 6: TRIPP Stage 3 – Develop preventive measures**

**Table 1** Data extraction of the included studies in stage 3 of the TRIPP framework. *DH: downhill; EC: European Cup; F: female/s; FIS: International Ski and Snowboarding Federation; GRF: ground reaction forces; GS: giant slalom; M: male/s; NMT: neuromuscular training; SG: Super-G; SL: slalom; WC: World Cup; WOG: Winter Olympic Games.*

| **Study features** | **Aim of the study** | **Sample characteristics** | **Study context** | **Injury data** | **Injury etiology** | **Injury prevention strategy** | **Implementation data** | |
|---|---|---|---|---|---|---|---|---|
| **Author, year, study design, country/federation** | | **a) Sample size (n)<br>b) Gender<br>c) Age** | **a) Competition level (alpine skiing discipline)<br>b) Time of the season/year** | **a) Injury definition<br>b) Injury reporting method** | **Injury mechanisms and/or inciting events** | **Description** | **a) Compliance/adherence definition<br>b) Compliance/adherence rate** | **c) Implementation context description** |
| Anghileri M et al., 2014[47]<br>Experimental lab study | to demonstrate that numerical simulations can be used to support the design of safety net systems, reduce the number of tests to perform for the certification, and, hence, reduce time and cost associated to with the development of high standard safety nets. | | | | | Design and development of high standard safety net systems | | |
| Bergeron MF et al., 2012[54]<br>Consensus | to highlight selected key environment-related risk factors that continue to challenge Olympic and other international-level athletes; and to re-emphasise and provide additional recommendations to address and minimise those | | | | | No competitions below -27C; Combination of air temperature and wind speed, plus the speed of the competitor. | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | risks associated with recent and ongoing incidents of environmentally prompted illness, injury and death in sport. | | | | | | | |
| Gilgien M et al., 2020[81] Cross-sectional study | to assess how course-setting characteristics, entrance speed and terrain incline influence the mechanics of turning (i.e., turn speed, turn radius, and ground reaction force and impulse); and to determine whether manipulation of horizontal gate offset or vertical gate distance is a more reasonable way to reduce speed and risk of injury in real WC alpine GS races. | a) n=6 | a) Former WC or current EC racer (GS)<br>b) Multiple winter seasons | | | Speed reduction of 0.5 m/s by decreasing the vertical gate distance (20 to 29%) in GS, with less adverse side effects on safety than increasing the horizontal gate offset (33 to 55%) | | |
| Gilgien M et al., 2021[82] Cross-sectional study | to assess whether course-setting characteristics, entrance speed and terrain incline influence speed through a turn; and to assess whether changes in course-setting aimed at reducing speed have negative consequences on turn radius, impulse and turn forces in Super-G. | a) n=4 | a) WC-level (SG)<br>b) Multiple winter seasons | | | Speed reduction of 0.5 m/s by decreasing the vertical gate distance (13%) in Super-G, with less adverse side effects on safety than increasing the horizontal gate offset (51%) | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Gilgien M et al., 2018[85] Cross-sectional study | to capture the external forces acting on forerunners skiing World Cup races in GS, SG and DH. | b) M<br>c) 25.1 ± 3.5 | a) Forerunners: former male WC-level or current EC-level (GS, SG and DH)<br>b) Winter season | | | Speed reduction by increasing ski-snow friction force in GS and SG, while increasing ski-snow friction force is as effective as increasing air drag force in DH | | |
| Gilgien M et al., 2016[86] Experimental lab study | to investigate the effect of modifications in ski geometry (ski length, ski width) and standing height of DH skis on speed and kinetic energy while skiing a WC DH course. | a) n=2<br>b) M<br>c) 34.5 ± 4.5 | a) Retired WC athletes (DH)<br>b) Winter season | | | Reducing kinetic energy by approximately 3% with longer skis with reduced standing height and reduced profile width in steep terrain as in DH | | |
| Kashluba KA (2018)[110] Quasi-experimental study Canada | to investigate if a neuromuscular training (NMT) warm-up program during preseason conditioning in Southern Alberta ski-clubs would improve lower limb balance and maximal muscular power when compared to a standard preseason program in alpine ski-racers 10-13 years old (U14). | a) n=84<br>b) F45, M39<br>c) F11.4 (10.9, 11.8 99% CI), M10.9 (10.5, 11.4 99% CI) | a) U12, U14<br>b) Prior competition season | | | NMT warm-up program during preseason to improve lower limb balance and maximal muscular power (15-20 minutes program, twice a week during 8 weeks, consisting of 10 exercises) | a) Adherence reported by attendance to the program, recorded by each ski-clubs' designated personnel over the 8-weeks. Each participant was to attend a total of 16 sessions<br>b) Adherence: 34%; loss to follow-up: 28% | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Kröll J et al., 2016[114] Experimental field study | to provide the decision makers of FIS with an evidence-based foundation for equipment specification changes in giant slalom (GS) by verifying the achievability of the following goal: GS specific injury prevention by a reduction of the ski's aggressiveness, and maintaining the external attractiveness of ski technique to spectators. | a) Exp 1: n=13; Exp 2: n=7<br>b) M | a) Exp1: EC- and WC-levels; Exp2: WC-level (GS)<br>b) Winter season | | | Reduction of kinetic energy with longer skis with higher sidecut radius and reduced profile width in GS. Greater sidecut radius relates to a reduction in subjective perceived aggressiveness | | |
| Kröll J et al., 2016[115] Experimental field study | to investigate the effect of sidecut radius on the characteristics of kinetic energy within a multigate section in giant slalom (GS). | a) n=5<br>b) M | a) EC-level (GS)<br>b) Winter season | | | Reducing kinetic energy by 5.6 to 8.8% with skis with higher sidecut radius both on flat and steep terrain in GS | | |
| Mössner M et al., 2009[119] Experimental lab study | to investigate the influence of ski stiffness on the trajectory of the skier performing a sequence of turns. | | | | | Skis with reduced torsional stiffness relates to larger penetration depth into the snow due to larger edge angles, reducing skidding and turn radius | | |
| Müller E et al., 2016[120] Editorial | | | | | | Introduction of new equipment rules by FIS for the 2012–2013 season: longer skis with less-shaped skis (higher sidecut radius) and reduced profile width | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Petrone N et al., 2012[130] Experimental laboratory study | to develop a full-scale impact test method suitable for safety barriers commonly installed during Ski World Cup events. | | a) WC-level | | | Design and development of high standard safety net systems | | |
| Petrone N et al., 2008[131] Experimental lab study | to develop a full-scale test method for performing impact tests under controlled conditions on the safety barriers usually adopted during the ski world cup events at the arrival arena. | | a) WC-level | | | Design and development of safety net systems for the arrival arena | | |
| Spörri J et al., 2016[145] Experimental field study | to investigate the effect of increased gate offsets on the biomechanical variables related to spinal disc loading in GS and SL; and to compare the aforementioned variables between these competition disciplines. | a) n=10 | a) WC-level and EC-level (GS and SL) b) Winter season | | | Lower back peak GRFs by increasing horizontal gate offset by 50% (from 3 m to 4.5 m) in SL | | |
| Spörri J et al., 2018[146] Experimental field study | to assess the effect of reduced standing height on the overall trunk kinematics and occurring ground-reaction forces in alpine GS from an overuse injury prevention perspective. | a) n=7 | a) EC-level (GS) b) Winter season | | | Lower overall back GRF of 2.5% with skis with a 10 mm-lower standing height (20%) in GS | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Spörri J et al., (2016)[148] Experimental field study | to investigate the effect of skis with different sidecut radii on variables related to the mechanics of turning in giant slalom (GS); and to discuss the findings in the context of injury prevention in alpine ski racing. | a) n=6 | a) EC-level (GS) b) Winter season | | | Lower GRF and reduced ski self-steering with skis with higher sidecut radius in GS | | |
| Spörri J et al., 2019[151] Editorial | | | | | | Machine-groomed snow preparation to reduce low-frequency whole-body vibrations and acting back GRFs in SL | | |
| Supej M et al., 2017[20] Editorial | | | | | | Improve safety by improving the safety-release in ski bindings and the planning and regulation of terrains and courses in competitions | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tang W et al., 2022[169]<br>Case report study | to analyse the components and dynamic characteristics of alpine skiing; to construct an "Object-Characteristic-Relation" representation model to express multi-level knowledge; and to propose a "Characteristic value-Relationship" representation method based on the multisource data to construct the knowledge graph of alpine skiing. | | a) WOG event<br>b) Winter season | | | Suspension of events when temperatures are higher than 2°C or lower than -25°C, or showers with a strong wind faster than 15 m/s | | |

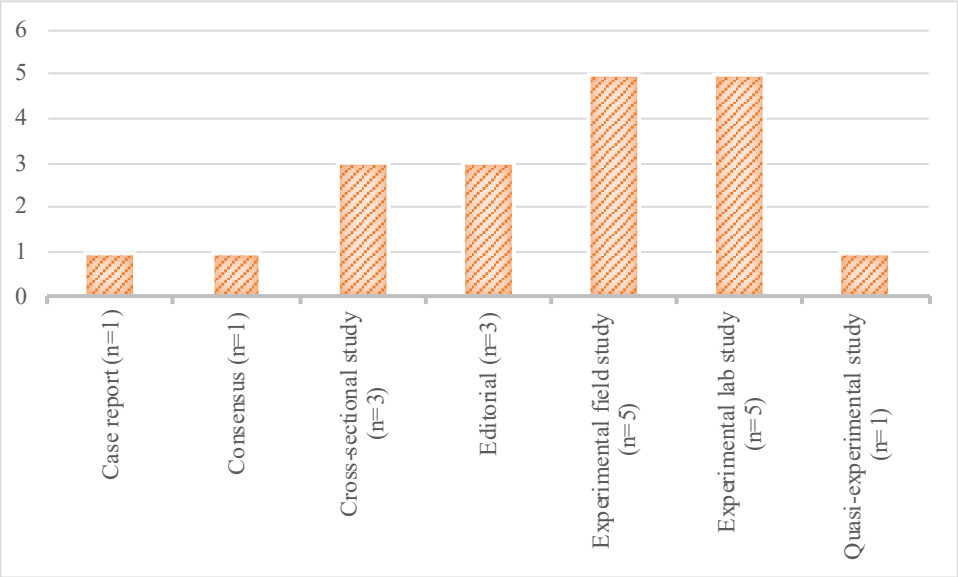


**Fig 1** Study designs of the included studies in stage 3 of the TRIPP framework.

**Supplementary information 7: TRIPP Stage 4 – "Ideal conditions"/scientific evaluation**

**Table 1** Data extraction of the included studies in stage 4 of the TRIPP framework. *ACL: anterior cruciate ligament; CG: control group; F: female/s; FIS: International Ski and Snowboarding Federation; GS: giant slalom; IG: intervention group; M: male/s; NMT: neuromuscular training; SL: slalom; WC: World Cup.*

| Study features | Aim of the study | Sample characteristics | Study context | Injury data | Injury etiology | Injury prevention strategy | Implementation data | |
|---|---|---|---|---|---|---|---|---|
| Author, year, study design, country/federation | | a) Sample size (n)<br>b) Gender<br>c) Age | a) Competition level (alpine skiing discipline)<br>b) Time of the season/year | a) Injury definition<br>b) Injury reporting method | Injury mechanisms and/or inciting events | Description | a) Compliance/adherence definition<br>b) Compliance/adherence rate | c) Implementation context description |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Kashluba KA (2018)[110] Quasi-experimental study Canada | to investigate if a neuromuscular training (NMT) warm-up program during preseason conditioning in Southern Alberta ski-clubs would improve lower limb balance and maximal muscular power when compared to a standard preseason program in alpine ski-racers 10-13 years old (U14). | a) n=84<br>b) F45, M39<br>c) F11.4 (10.9, 11.8 99% CI), M10.9 (10.5, 11.4 99% CI) | a) U12, U14<br>b) Prior competition season | | | NMT warm-up program during preseason to improve lower limb balance and maximal muscular power (15-20 minutes program, twice a week during 8 weeks, consisting of 10 exercises) | a) Adherence reported by attendance to the program, recorded by each ski-clubs' designated personnel over the 8-weeks. Each participant was to attend a total of 16 sessions<br>b) Adherence: 34%; loss to follow-up: 28% | |
| Kröll J et al., 2017[18] Editorial | to discuss a recently implemented preventive measure in alpine ski racing as an example; to highlight the influence of sample size and effect size on study power and the possibility for statistical hypothesis testing; and to provide a solution to increase study power for comparable injury prevention initiatives in elite sports. | | a) WC-level | | | Introduction of new equipment rules by FIS for the 2012–2013 season: Longer skis with less-shaped skis (higher sidecut radius) and reduced profile width | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Westin M et al., 2020[178] Prospective cohort study (intervention study with historical controls) Sweden | to evaluate whether a sports specific prevention program including different exercises could reduce the incidence of ACL injuries in competitive adolescent alpine skiers. | a) n=736 (IG n=305; CG n=431)<br>b) IG: F157, M148; CG: F216, M215<br>c) IG: 17.1 ± 1.14; CG: 17.5 ± 1.23 | a) Youth level (GS and SL)<br>b) Multiple seasons | | | Educational and exercise-based ACL injury prevention video program. First year: watching the video every third week during preseason and once a month during competition season. Three indoor and three on-snow exercises on core stability and neuromuscular control. | a) Compliance was collected through a questionnaire<br>b) 42% answered the questionnaire about their compliance and 75% watched the video 1-5 times | |

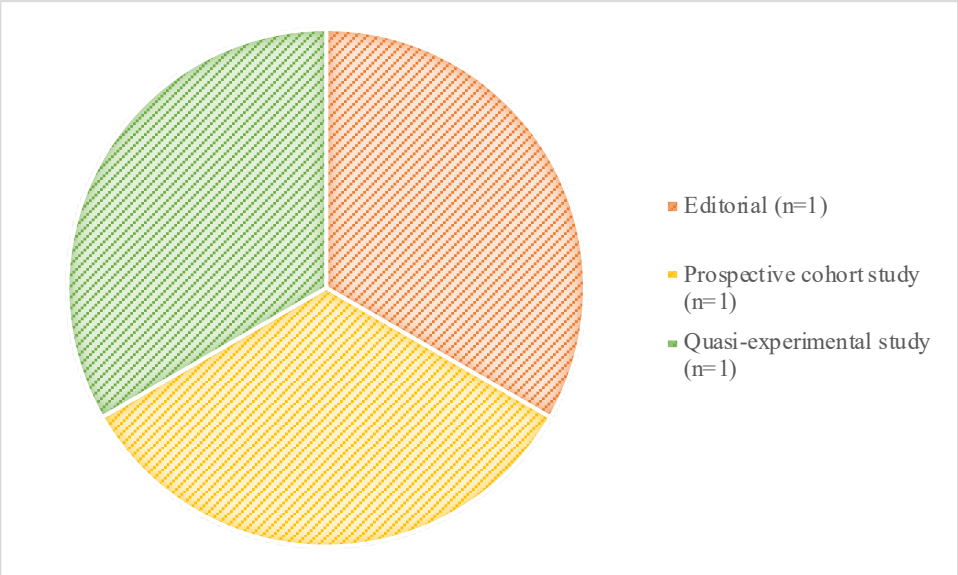


**Fig 1** Study designs of the included studies in stage 4 of the TRIPP framework.

**Supplementary information 8: TRIPP Stage 5 – Describing the intervention context to inform implementation strategies**

**Table 1** Data extraction of the included studies in stage 5 of the TRIPP framework. *DBB: deadbug bridging exercise; EC: European Cup; F: female/s; FIS: International Ski and Snowboarding Federation; M: male/s; SRC: sports-related concussion; WC: World Cup; WOG: Winter Olympic Games.*

| **Study features** | | **Sample characteristics** | **Study context** | **Injury data** | **Injury etiology** | **Injury prevention strategy** | **Implementation data** | |
|---|---|---|---|---|---|---|---|---|
| **Author, year, study design, country/federation** | **Aim of the study** | **a) Sample size (n)<br>b) Gender<br>c) Age** | **a) Competition level (alpine skiing discipline)<br>b) Time of the season/year** | **a) Injury definition<br>b) Injury reporting method** | **Injury mechanisms and/or inciting events** | **Description** | **a) Compliance/adherence definition<br>b) Compliance/adherence rate** | **c) Implementation context description** |
| Bere T et al., 2014[21]<br>Editorial | | | a) WC-level | | | Establishment of safety culture: FIS Injury Surveillance System (2006-07) | | |
| Chang JY et al., 2021[60]<br>Case study | to provide an in-depth analysis of physiotherapy treatments to athletes during the Olympic Winter Games at the two polyclinics; and to have a better understating of the levels and the patterns of physiotherapy services in each polyclinic. | a) n=322<br>b) F42, M83 (of total n=125 visitors) | a) WOG<br>b) Winter season | b) Electronic report forms in the WOG events[52] | | | | Athletes who visited the physiotherapy services during the 2018 PyeongChang Olympic Winter Games. 17 sport physiotherapists and 2 team leaders from the Korean Physical Therapy Association. Main reasons accounted for injury rehabilitation (48.3%), recovery (44.8%), and injury prevention (6.9%). Causes of injury were: overuse (49.4%), previous injury (29.9%), fall (6.9%), contact with an object (6.9%), non-contact trauma (4.6%), and equipment (2.3%). Encounter rate per 1000 athletes: 180.1 (n= 322 alpine ski racers). Type of treatments provided: electrophysical modalities (34.7%), |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | treatment exercise (21.5%), soft tissue technique (14%), joint manipulation/mobilisation (13.2%), strapping/taping (7.2%), cryotherapy (4.2%), verbal advice and guidance (2.6%), and general massage (2.3%). |
| Kiers K et al., 2021[29] Cross-sectional study (descriptive) | to update experts' priorities of perceived key injury risk factor categories in alpine ski racing based on a framework derived 10 years ago; to assess potential priority differences among expert subgroups in dependency of their stakeholder roles the level of competition at which they operate; to identify additional emerging risk factors; and to compile a list with countermeasure suggestions for all risk factors reported. | a) n=532 | a) WC-level, EC-level, FIS-competitions level<br>b) Off-season | | | | | Experts' perceptions on key injury risk factors in alpine ski racing depend on the stakeholder role and differ between the competition levels (WC, EC, FIS competitions).<br>5 expert stakeholder groups and different level and professional background from 28 countries:<br>- Alpine ski racers (n=298 from WC-, EC-, and FIS competitions levels);<br>- Coaches (n=130 from WC-, EC-, and FIS competitions levels);<br>- Team medical staff (n=59 including doctors, physiotherapists, and other professionals);<br>- Ski racing supplier representatives (n=33 including service men, research & development and management, and other professionals); and<br>- FIS representatives (n=12 including FIS staff for competitions, committee members, and other representatives) |
| Maxwell N et al., 2020[117] Editorial and qualitative study Switzerland | to better understand alpine ski racing athletes' perceptions, beliefs and experiences of sports-related concussion. | a) n=11 | a) Competitive level | | | (1) Educating athletes on sports-related concussion to recognise the presence of SRC and the importance of communicating symptoms of SRC and reduce the threat of premature return-to-play; and (2) educating | | Athletes representing Swiss-Ski. Sports-related concussion (SRC) is the most frequent head injury in alpine ski racing. Major shortfalls in alpine ski racing athletes' understanding of SRC were identified in the areas of: (1) the definition of concussion; (2) athletes' awareness of the connection between SRC and affective symptom; (3) diagnostic |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | coaches and supporting staff on their understanding of SRC for athletes' decision-making process and accompanying athletes in their return-to-play process. | | tools; and (4) athletes' understanding of the reasoning behind graduated return-to-play protocols. |
| Stainsby B et al., 2014[155] Cross-sectional study (descriptive) Canada | to explore the attitudes and actions of Canadian alpine ski racing coaches regarding spinal protective devices. | a) n=29<br>b) F and M | a) Canadian Ski Coaches Federation | | | | b) Only 23% of the 126 coaches fully responded. | Canadian provincial alpine skiing racing coaches through Canadian Ski Coaches Federation training athletes aged 10-15.<br>Lack of use of spinal protective devices (51.7% do not actively enforce their use), and lack of guidelines and policies regarding their use (80% reported ignorance or unawareness of specific guidelines or policies). |
| Strutzenberger G et al., 2022[165] Cross-sectional study Switzerland | to investigate the implementability of the DBB exercise in 6- to 15-year-old competitive alpine skiers and to determine their DBB performance as a function of age group and sex; to investigate the associations of DBB performance with age, anthropometrics and maturity offset. | a) n=101 (U10 n=50; U15 n=61)<br>b) F58, M43 (U10= F31, M19; U15= F27, M24)<br>c) Range 6-15 | a) U10, U15<br>b) Off-season | | | Deadbug bridging (DBB) exercise: antirotation and rear-chain stabilisation capacity. | | 6-to 15-year-old Swiss competitive alpine skiers taking part of a physical fitness competition during the 2021 off-season period. Prior the event, participants had access to a video tutorial to practice and be familiarised with the DBB exercise. DBB is a low dynamic closed-chain stabilisation exercise addressing typical components of mechanisms leading to back overuse injuries in alpine ski racing. |

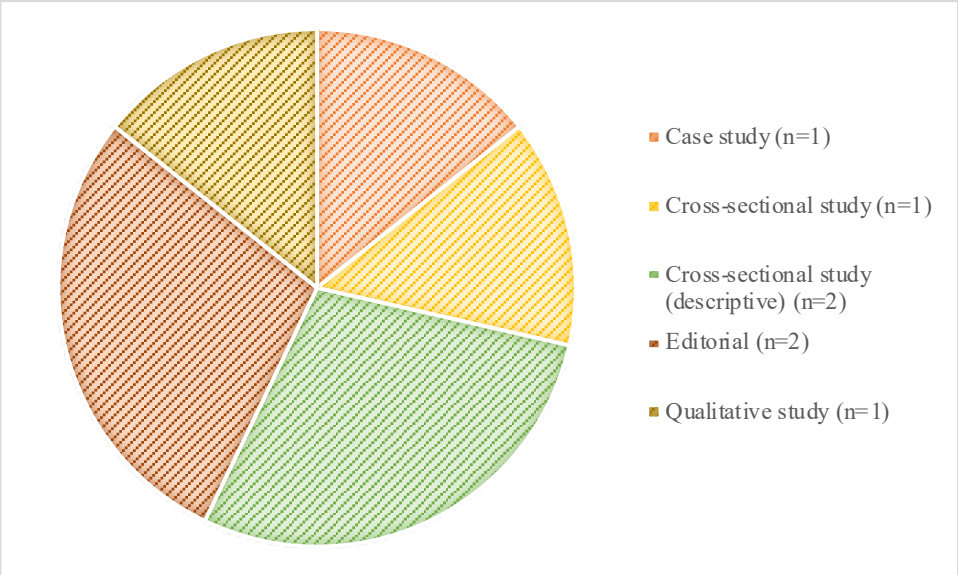


**Fig 1** Study designs of the included studies in stage 5 of the TRIPP framework.

**Supplementary information 9: TRIPP Stage 6 – Evaluate the effectiveness of preventive measures in the implementation context**

**Table 1** Data extraction of the included studies in stage 6 of the TRIPP framework. *CG: control group; EC: European Cup; F: female/s; IG: intervention group; M: male/s; OSTRC: Oslo Sports Trauma Research Center; WC: World Cup; WOG: Winter Olympic Games.*

| **Study features** | | **Sample characteristics** | **Study context** | **Injury data** | **Injury etiology** | **Injury prevention strategy** | **Implementation data** | |
|---|---|---|---|---|---|---|---|---|
| **Author, year, study design, country/federation** | **Aim of the study** | **a) Sample size (n)**<br>**b) Gender**<br>**c) Age** | **a) Competition level (alpine skiing discipline)**<br>**b) Time of the season/year** | **a) Injury definition**<br>**b) Injury reporting method** | **Injury mechanisms and/or inciting events** | **Description** | **a) Compliance/adherence definition**<br>**b) Compliance/adherence rate** | **c) Implementation context description** |
| Haaland B et al., 2016[12]<br>Time trend analysis (based on retrospectively acquired data) | to investigate the effect of the new ski regulations on the rate and pattern of injuries by comparing data before (2006–2012) and after (2012–2015) their implementation. | a) n=2402<br>b) F1058, M1344 | a) WC-level (all disciplines)<br>b) Multiple winter seasons | a) Fuller CW et al., definitions[45,46]<br>b) FIS Injury Surveillance System (ISS) based on annual retrospective interviews[19] | | Introduction of new equipment rules by FIS for the 2012–2013 season: Longer skis with less-shaped skis (higher sidecut radius) and reduced profile width | | Data analysed during nine WC seasons (2006-2015) in the final event of each season. Athletes must have started in at least one WC or World Ski Championship (WSC) event throughout the season, and must be identified by the head coach as an official member of the WC team to be included. Injuries occurred during both races and official trainings to WC, WSC, WOG, FIS and other competitions or on-snow trainings were registered. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Platzer HP et al., 2021[133]<br>Case study<br>Austria | to assess the effect of the FIS equipment regulations of the years 2003, 2007 and 2012 on severe injury incidence. | a) n=1725 (WC n=727; EC n=536, Junior n=462)<br>b) F774, M951<br>c) Junior to adults | a) WC-level, EC-level and Junior (all disciplines)<br>b) Multiple seasons | a) Other and tailored definitions: severe injury[133]<br>b) Paper-and-pencil questionnaire; Online questionnaire (Austrian Ski Team) - Internet-based database[2] | | Evaluation of the introduced new equipment rules by FIS in 2002/2003, 2006/2007 and 2011/2012 | | Data analysed over four time periods in males and females from the Austrian Ski Federation:<br>(1) 2001-2003 seasons in all competition levels;<br>(2) 2004-2007 seasons in all competition levels;<br>(3) 2008-2012 seaons in World Cup and Europa Cup athletes, and 2008-2013 in National junior athletes;<br>(4) 2013-2017 seasons in World Cup and Europa Cup athletes, and 2014-2017 seasons in National junior athletes.<br>Seasons beginning May 1st and ending April 30th of the following year.<br>A higher significant incidence of the total severe injury events in the four seasons after the 2002/2003 equipment regulation introduction (greater sidecut radius in downhill skis in both sexes and reduced ski boot sole thickness in males) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Schoeb T et al., 2022[140] Experimental field study Switzerland | to introduce a novel injury prevention programme targeted to the specific injury patterns of youth competitive alpine skiers of the U16 category, hereinafter called ISPAInt (short for "Injury Screening and Prevention—Alpine Skiing"); and to compare the differences in injury occurrence between an intervention group additionally performing the ISPAInt programme once a week over a 12-month period in their real-world training setting and age-matched controls following their regular training routines. | a) n=129 (IG n=71, CG n=58)<br>b) Female/male ratio: IG=0.82, CG=0.81<br>c) 14.4 ± 0.3 | a) U16<br>b) Multiple seasons | a) OSTRC definitions[49,50]<br>b) OSTRC questionnaire on health problems (and retrospective interviews) [49,50] | | Training programme: alpine skiing-specific injury mechanisms programme (ISPAint programme): 20-min home training programme, once a week during one year, consisting of three exercise families: eccentric hamstring strength, leg axis stability by strengthening external hip rotators, and trunk stability. | a) Participants' adherence to this recommendation was surveyed but not enforced. The IG participants' adherence to the ISPAInt programme was assessed by an additional question attached to the OSTRC questionnaire.<br>b) Adherence rate: 0.8 ± 0.6 sessions/week; dropouts due to quitting sports career in the enrolment procedure: 29% | U16 alpine skiers from the Swiss-Ski (certified regional performance centre [RLZ/CRP] of Swiss-Ski, representing the best skiers of their age) |

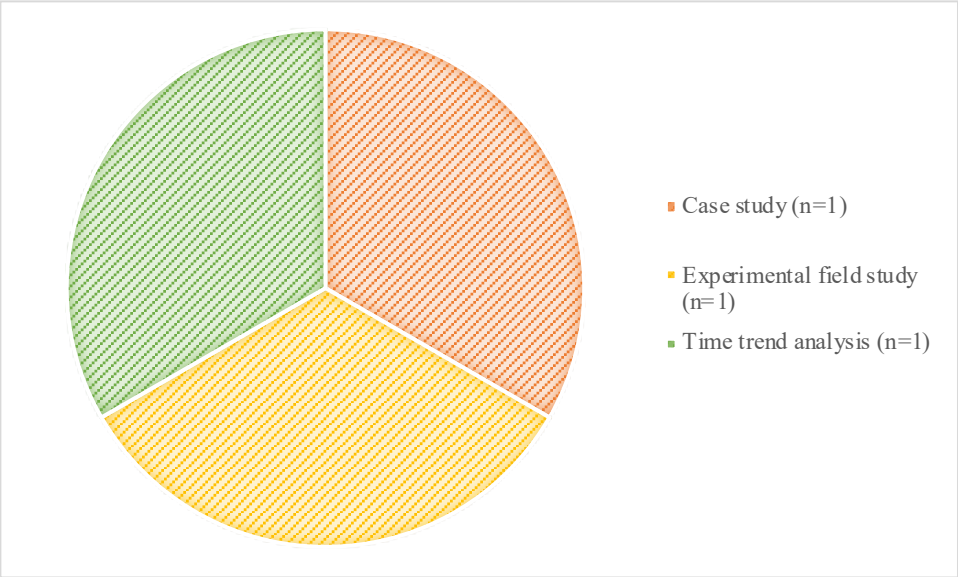


**Fig 1** Study designs of the included studies in stage 6 of the TRIPP framework.