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1 RISK FACTORS FOR INJURY IN SPORT CLIMBING AND BOULDERING:

2 A SYSTEMATIC REVIEW OF THE LITERATURE

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1                   **RISK FACTORS FOR INJURY IN SPORT CLIMBING AND BOULDERING:**

2                   **A SYSTEMATIC REVIEW OF THE LITERATURE**

3                   **ABSTRACT**

4                   **Background:** Rock climbing is an increasingly popular sport worldwide, as both a recreational activity  
5 and a competitive sport. Several disciplines including sport climbing and bouldering have developed,  
6 each employing specific movements and techniques, leading to specific injuries.

7                   **Objective:** To examine risk factors and prevention measures for injury in sport climbing and bouldering,  
8 and assess the methodological quality of existing studies.

9                   **Methods:** Twelve electronic databases and several other sources were searched systematically using  
10 predetermined inclusion and exclusion criteria. Eligible articles were peer-reviewed, based on primary  
11 research using original data; outcome measures included injury, morbidity or mortality in rock climbing,  
12 and included one or more potential risk factor or injury prevention strategy. Two independent reviewers  
13 assessed the methodology of research in each study using the Downs and Black Quality Index. The data  
14 extracted is summarized, and appraisals of the articles are presented with respect to the quality of  
15 evidence presented.

16                   **Results:** Nineteen studies met the inclusion criteria, and introduced 35 possible risk factors or injury  
17 prevention measures in climbing. Age, increasing years of climbing experience, highest climbing grade  
18 achieved (skill level), high Climbing Intensity Score (CIS), and participating in lead climbing are  
19 potential risk factors. Results regarding injury prevention measures remain inconclusive.

20                   **Discussion:** This field is relatively new and as such, the data are not as robust as for more established  
21 sports with a larger research foundation. The key need is establishing modifiable risk factors using  
22 prospective studies and high quality methodology, such that injury prevention strategies can be  
23 developed. The climbing intensity score (CIS) may be a useful measure in this field of research.

**New Findings:**

- Risk factors for acute and overuse injury in climbers may include age, increasing years of climbing experience, skill level, and participating in lead climbing.
- Injury prevention strategies targeting modifiable risk factors should be developed, including controlling climbing volume and intensity.
- The climbing intensity score (CIS) measures the degree of exposure to “climbing stress” of an individual. CIS scores have been introduced and used only in two studies to date, but both have indicated that participants who scored higher in CIS to be at a higher injury risk. This will be a measure to further examine and use in future research.

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2  
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Pre-publication

1 **INTRODUCTION**

2 Rock climbing is a popular sport worldwide, both as a recreational activity and as a competitive  
3 sport. Several disciplines of the sport exist, including traditional climbing, sport climbing, and  
4 bouldering.[1,2] Sport climbing and bouldering, the newest disciplines, are performed on artificial  
5 surfaces and on natural rock. Sport climbing routes are typically up to 30 metres high. The climber is  
6 attached to a rope clipped into permanent bolts using “quickdraws,” spaced intermittently from the  
7 bottom up (lead climbing), or the rope is anchored at the top of the climb (top roping), to allow climbers  
8 to incur frequent falls safely. Bouldering uses crash mats instead of ropes to protect climbers from falls.  
9 “Boulder problems” are usually short and low to the ground.

10 As sport climbing and bouldering employ specific movements and techniques, these two climbing  
11 disciplines lead to specific injuries. Previous research, involving primarily adult populations, suggests that  
12 upper extremity overuse injuries and acute flexor tendon pulley strains of the fingers are the most  
13 common injuries sustained by rock climbers in varying disciplines, though ankle injuries are also  
14 common due to falls .[3–9] There have been no reviews examining specific risk factors for injury in sport  
15 climbing and bouldering. By identifying potentially modifiable risk factors for these injuries, it may be  
16 possible to develop and evaluate injury prevention strategies. We systematically reviewed intrinsic and  
17 extrinsic risk factors and prevention strategies for injury in sport climbing and bouldering.

18

19 **METHODS**

20 **Information Sources**

21 Twelve electronic databases were searched systematically for relevant documents during  
22 November 2012, and the search was updated in December 2014: PubMed (1960–present), MEDLINE  
23 (OVID) (1946–present), SPORTDiscus (1960–present), BIOSIS Previews (1980–present), CINAHL Plus  
24 (1960–present), Academic Search Complete (EBSCO) (1960–present), PsychInfo (1967–present),  
25 ScienceDirect (Elsevier) (1960–present), Health STAR (1980–present), EMBASE (1974–present),  
26 SafetyLit ([www.safetylit.org](http://www.safetylit.org)), and Statistics Canada (<http://statcan.summon.serialssolutions.com>). Four

1 websites were searched for additional relevant publications: the UIAA (www.theuiaa.org), the  
 2 International Federation of Sport Climbing (IFSC) (www.ifsc-climbing.org), the Alpine Club of Canada  
 3 (ACC) (http://www.alpineclubofcanada.ca) and *The Alpine Journal* (a flagship publication of the ACC).  
 4 Articles were also obtained from a comprehensive collection provided at the annual 2012 Banff Climbing  
 5 Conference. Bibliographies of selected articles were searched for additional relevant publications. The  
 6 terms used for article extraction are found in Table 1.

7 **Table 1. Medical subject headings and text words used for article extraction**

Medical subject headings (MeSH) (also used as text words in each search)	Text words (tw)
1. "Mountaineering" 2. "Wounds and injuries" 3. "Athletic injuries" 4. "Risk factors"	5. "Climb" [Boolean climb*] 6. "Boulder" [Boolean boulder*] 7. "Injury" 8. "Sport injury" 9. "Prevention" 10. "Intervention" 11. "Safety"

8  
 9 *Search Strategy*

10 Climbing search terms: 1 OR 5 OR 6

11 Injury search terms: 2 OR 3 OR 7 OR 8

12 Risk factors: 4

13 Injury prevention search terms: 9 OR 10 OR 11

14 A. climbing and injury: A AND B

15 B. climbing and risk factors for injury: E AND C

16 C. climbing and injury prevention: E AND D

17 D. climbing, risk factors for injury, and prevention: F AND D

18 Search terms for climbing, injury, risk factors, and injury prevention were not searched individually as  
 19 they each yielded a high number of articles that were not specific to the topic of interest. Strategies A to D  
 20 were used to search each electronic database. If fewer than 300 articles were obtained, titles were

1 screened, abstracts reviewed to retrieve relevant articles, and duplicates removed. Finally, the full texts of  
2 the remaining articles were reviewed to assess eligibility based on the inclusion and exclusion criteria.

### 3 **Eligibility Criteria**

4 Study inclusion criteria were: articles based on primary research using original data; outcome  
5 measure included injury, morbidity or mortality in rock climbing (indoor or outdoor); included one or  
6 more potential risk factor or injury prevention strategy; designs included randomized controlled trials,  
7 quasi-experimental, cohort, cross-sectional, case-control, longitudinal, and case series studies; peer  
8 reviewed, and published in English. Review articles and case studies were excluded; however, reference  
9 lists of review articles were reviewed for additional relevant articles.

10 Two independent reviewers completed the review of selected articles during December 2012, and  
11 again in December 2014 for the additional articles. Each reviewer screened the full text articles to  
12 determine whether all inclusion criteria were met. Disagreements were resolved by discussion and  
13 subsequent consensus.

### 14 **Data Collection Process**

15 Descriptive data were extracted from studies that met all inclusion criteria. Study design,  
16 population, definition of injury, injury incidence, risk factor(s) examined, and results were extracted  
17 (Table 2). Risk factors and prevention measures for sport climbing were considered separately from those  
18 examined for bouldering, though not all articles specified, and thus discipline could not always be  
19 isolated. Injury incidence was examined to give context to the risk factor analysis (Table 3).

20 Two independent reviewers assessed each study using the Downs and Black criteria for methodological  
21 quality. Downs and Black includes a 27-item checklist for both randomized and non-randomized study  
22 designs. It aids in evaluating the quality of reporting, external validity, internal validity, and power.[10]  
23 The reviewers reached consensus for each article. The Oxford Centre for Evidence-Based Medicine Levels of  
24 Evidence were also determined for each study.[11]

### 25 **Data Synthesis**

1 Due to the diversity of objectives, methodology, and statistical analyses in these studies, meta-  
2 analyses to calculate injury rates or to quantitatively establish risk factors and prevention measures were  
3 not appropriate to carry out for this review. Therefore extracted data are descriptive. Relevant data are  
4 summarized, and appraisals of the articles are presented with respect to the quality of evidence presented.  
5

## 6 **RESULTS**

### 7 **Study Selection**

8 Titles and abstracts from database searches (n=149) and other sources (i.e., websites, conference,  
9 bibliographies) (n=54) were screened for inclusion and duplicates removed. The full texts of 49 articles  
10 were reviewed to assess each for eligibility; 19 studies met the inclusion criteria. Figure 1 summarizes the  
11 study selection process.

### 12 **Methodological Quality Assessment**

13 Study appraisal based on the Downs and Black criteria produced scores ranging from six to 15 out  
14 of 32 possible points (Table 2). Overall quality was low as the majority of the studies were cross-sectional  
15 (n=16). Furthermore, though the disciplines of sport climbing and bouldering were the focus of this  
16 review, results were included from studies that did not specify the type of climbing examined, as it was  
17 likely that they included sport climbing and bouldering, among others. Often, all “rock climbers” willing  
18 to participate were included in a study, and some samples may therefore have been less representative of  
19 the target population being examined for this review. The authors thought it better to include rather than  
20 exclude these studies and risk overlooking potential risk factors. Age ranges varied, and there was sex  
21 disparity in most studies, with samples composed of approximately 60-100% males.[2,12] Several studies  
22 failed to adjust for confounding variables, introducing potential bias in the results. Study quality scores  
23 and the Oxford Centre for Evidence-Based Medicine Levels of Evidence are summarized in Table 2.

1 **Table 2. Characteristics and results of studies examining risk factors for injury in sport climbing and bouldering**

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Backe <i>et al.</i> (2008) [13]	Cross-sectional	Swedish Climbing Association members n=355 (70% male, 30% female) Ages 9-67 years	4	15	Sport climbing and bouldering	“Injuries that occurred while participating in a climbing activity indoors or outdoors and that resulted in an injury treatment intervention (medical treatment, hospitalization and/or discontinuation and rest from climbing).” Traumatic injuries defined as acute onset, overuse injuries defined as repeated microtrauma without a single identifiable event.	Primary risk factor analysis for climbing injury: <ul style="list-style-type: none"> <li>• Body mass index (BMI): <math>p &lt; 0.015</math></li> <li>• Bouldering: <math>p &lt; 0.047</math></li> </ul> Risk factor analysis for re-injury (re-injury risk factors were used as a proxy for injury risk factors in the analysis): <ul style="list-style-type: none"> <li>• Time climbing per year: <math>p = 0.439</math></li> <li>• BMI: <math>p = 0.121</math></li> <li>• Sex (male): <math>p = 0.019</math></li> <li>• Age group (20-45 vs. &lt;20 yrs.): <math>p = 0.003</math></li> <li>• Age group (46+ vs. &lt;20 yrs.): <math>p &lt; 0.001</math></li> <li>• Bouldering: <math>p = 0.122</math></li> <li>• Sport climbing: <math>p = 0.719</math></li> <li>• Years climbing experience (5-9 vs. 0-4 yrs.): <math>p = 0.775</math></li> <li>• Years climbing experience (10+ vs. 0-4 yrs.): <math>p = 0.060</math></li> </ul>
Carmeli <i>et al.</i> (2002) [14]	Cross-sectional	Sport climbing club in Tel Aviv, Israel n=19 (67% male, 33% female) Ages 9-34 years	4	11	Sport climbing	Injuries sustained during sport climbing were self-reported soft tissue injury to the hands and fingers, classified by functional diagnoses (tendons and ligaments), and medical diagnoses	<ul style="list-style-type: none"> <li>• Sex (male): <math>p &lt; 0.05</math></li> <li>• Age (19-34 vs. 9-18 yrs.): significant (<math>p &lt; 0.05</math>)</li> <li>• Frequency: <math>p &lt; 0.05</math> (practicing 4-5x per week reported more diverse wrist and finger injuries)</li> <li>• Grip strength: <math>p &lt; 0.05</math> “mild to moderate correlation: <math>r = 0.26</math> and <math>r = 0.41</math>”</li> </ul>

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Gerdes <i>et al.</i> (2006) [15]	Cross-sectional	Rock climbers of any age, ability, or experience, primarily male, advanced or intermediate n=1887 (87% male, 13% female) Ages 10-66 years	4	9	All types of "rock climbing"	Subjects identified three most significant injuries. Data was collected on injured body part, type of injury, type of climbing, medical care sought, and recovery time.	<ul style="list-style-type: none"> <li>• Climbing discipline: more injuries in climbers participating in traditional climbing (mean 2.53 vs. 1.92; <math>p &lt; 0.001</math>) or free solo climbing (mean 3.30 vs. 2.09; <math>p &lt; 0.001</math>) (<i>traditional and free solo climbing are outside the scope of this systematic review</i>)</li> <li>• Indoors vs. outdoors: 47.7% and 52.3% of injuries (no test of hypothesis)</li> <li>• Familiar location versus unfamiliar/new area: 79.2% and 20.8% of injuries (no test of hypothesis) <ul style="list-style-type: none"> <li>○ 4.3% (95% Confidence Interval [CI]; 3.6, 5.2) injuries sustained by 'beginner' climbers</li> <li>○ 28.3% (95% CI; 26.6, 30.1) by 'intermediate' group</li> <li>○ 46.3% (95% CI; 44.4, 48.3) by 'advanced' group</li> <li>○ 21.2% (95% CI; 19.6, 22.9) by 'expert' group</li> </ul> </li> <li>• Use of illicit substances (while climbing): <math>p &lt; 0.008</math></li> </ul>
Hasler <i>et al.</i> (2012) [16]	Case-control	Indoor and outdoor climbers in Switzerland n=113 (76% of patients, 67% of controls male, 24% of patients, 33% of controls female) Ages 16-64 years	3b	13	All types of "rock climbing"	Acute injury from indoor or outdoor climbing where the climber was admitted to an emergency department. (Chronic overuse syndromes, intracranial bleeding, skull fractures, Glasgow Coma Score [GCS] of greater than 14 or persistent retrograde amnesia were excluded.)	<ul style="list-style-type: none"> <li>• Sex: <math>p &gt; 0.05</math></li> <li>• Age: <math>p &gt; 0.05</math></li> <li>• Level of difficulty of the climbing route: <math>p &gt; 0.05</math></li> <li>• Duration of warm-up: <math>p &gt; 0.05</math></li> <li>• Readiness for risk: <math>p &gt; 0.05</math></li> <li>• Abstinence from alcohol and drugs: <math>p &gt; 0.05</math></li> <li>• &gt;10 yrs. climbing experience (vs. &lt;1 yr.): <math>p &gt; 0.05</math></li> <li>• 1-10 yrs. climbing experience (vs. &lt;1 yr.): <math>p = 0.006</math>, Odds ratio (OR)=5.34, (95%CI; 1.61; 17.76)</li> <li>• No previous experiences on the climbing route: OR=2.72 (95%CI; 1.15, 6.39), <math>p = 0.022</math></li> </ul>

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Jones <i>et al.</i> (2008) [3]	Cross-sectional	British rock climbers n=201 (81% male, 19% female) Ages 16-62 years	4	11	All types of "rock climbing"	Injuries requiring medical attention or withdrawal from sport participation for more than one day	<ul style="list-style-type: none"> <li>• Age: <math>p &gt; 0.05</math></li> <li>• Sex (male): <math>p &gt; 0.05</math></li> <li>• Years climbing experience: <math>p &gt; 0.05</math></li> <li>• Soloing frequency: <math>p &lt; 0.05</math> for overuse injury, OR=1.79 (95% CI; 1.14, 2.83)</li> <li>• Soloing grade: <math>p &gt; 0.05</math></li> <li>• Traditional lead frequency: <math>p &gt; 0.05</math></li> <li>• Traditional lead grade: <math>p &lt; 0.05</math> for overuse injury, OR=1.25 (95% CI; 1.07, 1.46) <i>(traditional and free solo climbing are outside the scope of this systematic review)</i></li> <li>• Sport lead frequency: <math>p &lt; 0.05</math> for overuse injury, OR=1.49 (95% CI; 1.05, 2.13)</li> <li>• Sport lead grade: <math>p &lt; 0.05</math> for falls, OR=1.47 (95% CI; 1.04, 2.09); <math>p &lt; 0.05</math> for overuse injury, OR=1.28 (95% CI; 1.05, 1.56)</li> <li>• Indoor lead frequency: <math>p &lt; 0.05</math> for overuse injury, OR=1.21 (95% CI; 1.03, 1.42)</li> <li>• Indoor lead grade: <math>p &lt; 0.05</math> for overuse injury, OR=1.42 (95% CI; 1.17, 1.71)</li> <li>• Bouldering frequency: <math>p &lt; 0.05</math> for overuse injury, OR=1.24 (95% CI; 1.07, 1.43)</li> <li>• Bouldering grade: <math>p &lt; 0.05</math> for overuse injury, OR=1.42 (95% CI; 1.16, 1.73) and strenuous moves, OR=1.24 (95% CI; 1.02, 1.50)</li> </ul>

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Josephsen <i>et al.</i> (2007) [2]	Cross-sectional with a prospective cohort component	Boulderers in two cohorts: primarily indoor climbers and primarily outdoor climbers n=152 (60% male, 40% female) Mean age 25±5 years (range not reported)	2b	12	Bouldering	Not defined, divided by anatomical location and mechanism of injury	<p>Risk factor examination:</p> <p>For finger injuries (analyzed since it was the most common climbing injury, as opposed to falling):</p> <ul style="list-style-type: none"> <li>• Outdoor vs. indoor bouldering: higher outdoor (19 (61%) vs. 6 (27%); 95% CI for risk difference: -10, -3)</li> <li>• Previous history of finger injury: p=0.03, OR=4.0 (95% CI; 1.2, 13.6)</li> <li>• Sex: p&gt;0.05</li> <li>• Years climbing experience: p&gt;0.05</li> <li>• Body mass index (BMI): p&gt;0.05</li> <li>• Weight: p&gt;0.05</li> <li>• Climbing ability: p&gt;0.05</li> </ul> <p>For fall injuries:</p> <ul style="list-style-type: none"> <li>• Outdoor vs. indoor bouldering: higher indoor (7 (23%) vs. 11 (50%); 95% CI for risk difference: 2, -53)</li> <li>• Presence of spotters: p&gt;0.05</li> <li>• Number of spotters: p&gt;0.05</li> <li>• Height of average boulder: p&gt;0.05</li> <li>• Height of tallest boulder climbed: p&gt;0.05</li> <li>• Use of pads: p&gt;0.05</li> <li>• Years climbing experience: p&gt;0.05</li> <li>• BMI: p&gt;0.05</li> <li>• Weight: p&gt;0.05</li> <li>• Ability level: p&gt;0.05</li> </ul> <p>Prevention measure examination:</p> <ul style="list-style-type: none"> <li>• Warm-up (5, 10, and &gt;10 mins. examined): p&gt;0.05</li> <li>• Stretching: p&gt;0.05</li> <li>• Regular yoga practice: p&gt;0.05</li> </ul>

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Josephsen <i>et al.</i> (2007) <i>continued</i>							<ul style="list-style-type: none"> <li>• Finger taping: <math>p&gt;0.05</math></li> <li>• Wrist taping: <math>p&lt;0.05</math> (protective effect)</li> <li>• Glucosamine: <math>p&gt;0.05</math></li> <li>• Other supplement use: <math>p&gt;0.05</math></li> <li>• Heating hands prior to climbing: <math>p&gt;0.05</math></li> <li>• Taking time off to prevent injuries: <math>p&gt;0.05</math></li> <li>• Use of corticosteroid injections: <math>p&gt;0.05</math></li> <li>• Weight training: <math>p&lt;0.05</math> (protective effect)</li> <li>• Presence of spotters: <math>p&gt;0.05</math></li> <li>• Use of bouldering pads: <math>p&gt;0.05</math></li> </ul>
Limb (1995) [17]	Cross-sectional	Climbing facilities in England, Scotland, and Wales n=56 facilities (sex and ages of injured climbers not reported)	4	6	Indoor climbing (likely sport climbing and bouldering)	“Significant injuries”: requiring the injured party to be transported to a local casualty department for emergency treatment	<p>Risk factor examination:</p> <ul style="list-style-type: none"> <li>• Climbing styles had a relation to injury rates</li> <li>• Wall height had no relation to injury rates</li> <li>• Walls allowing soloing had no relation to injury rates</li> </ul> <p>Prevention measure examination:</p> <ul style="list-style-type: none"> <li>• Walls which instituted safety regulations had no relation to injury rates</li> <li>• Safety features had a relation to injury rates</li> <li>• Safety mats: <math>p&gt;0.05</math> for injury rate (<math>p&lt;0.05</math>, <math>X^2=4.57</math> upper limb injuries occurring on walls which provided fixed safety mats (11/14=78.57%))</li> </ul>
Logan <i>et al.</i> (2004) [9]	Cross-sectional	Members of the Climber’s Club of Great Britain n=545 (91% male, 9% female)	4	10	All types of “rock climbing”	Wrist or hand injury by type and severity	<ul style="list-style-type: none"> <li>• Climbing intensity score (CIS): <math>p=0.01</math></li> </ul>

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Logan <i>et al.</i> (2004) <i>continued</i>		Ages 23-93 years					
Nelson <i>et al.</i> (2009) [18]	Cross-sectional	Rock climbers in the US n=40 282 (70% male, 30% female) Ages 2-74 years	4	9	All types of "rock climbing"	Injuries presenting to a hospital emergency department in the United States.	<ul style="list-style-type: none"> <li>• Sex: Males more likely to sustain lacerations (OR=1.65; 95% CI; 1.03, 2.67) and fractures (OR=1.54; 95% CI; 1.10, 2.17)</li> <li>• Women more likely to sustain sprains/strains (OR=1.68; 95% CI; 1.13, 2.51)</li> </ul>
Neuhof <i>et al.</i> (2011) [4]	Cross-sectional	Sport climbers n=1962 (81% male, 19% female) Ages 13-60 years	4	12	Sport climbing	Acute injury only, sustained in sport climbing	<ul style="list-style-type: none"> <li>• Sex: p&gt;0.05</li> <li>• Age: p&gt;0.05</li> <li>• BMI: p&gt;0.05</li> <li>• Difficulty level: p&lt;0.01</li> <li>• Climbing experience: p&lt;0.01</li> <li>• Climbing time per week during summer months: p&lt;0.01</li> <li>• Climbing time per week during winter months: p&lt;0.01</li> </ul>
Paige <i>et al.</i> (1998) [1]	Cross-sectional	Traditional and sport climbers n=398 (86% male, 14% female) Ages 11-63 years	4	7	Traditional and sport climbing	Injuries occurring outdoors during either traditional or sport rock climbing (Only sport climbing injuries were used for the purpose of this review)	Of 48 sport climbing injuries: <ul style="list-style-type: none"> <li>• 38 (79%) were leading,</li> <li>• 8 (17%) were top roping,</li> <li>• 2 (4%) were belaying</li> </ul>

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Pieber <i>et al.</i> (2012) [19]	Cross-sectional	Sport climbers and boulderers in Austria n=193 (69% male, 31% female) Mean age of females 29.4±5.6 years, mean age of males 31.2±8.6 years (range not reported)	4	12	Sport climbing and bouldering	Injuries and overuse syndromes, classified by anatomical location, cause, diagnosis if known. Minor abrasions were excluded.	<ul style="list-style-type: none"> <li>• Sex (male): p=0.032</li> <li>• Age group (~29.5 yrs. vs. ~23 yrs.): p=0.021 (injury higher in older group)</li> <li>• Age group (~39.7 yrs. vs. ~29.5 yrs.): non-significant (p&gt;0.05)</li> <li>• Climbing intensity score (CIS) groups: p=0.000 (injury higher in higher intensity groups)</li> </ul>
Rohrbough <i>et al.</i> (2000) [5]	Cross-sectional	Elite competitive climbers in the U.S. n=42 (83% male, 17% female) Ages 13-40 years	4	12	Elite competitive climbing (likely sport climbing)	Upper extremity injuries only. Recorded by location of pain, type and difficulty of move that caused injury, duration and intensity of pain. Injuries sustained in a fall were not included.	<ul style="list-style-type: none"> <li>• Age: significant for A2 pulley pain only (p=0.004)</li> <li>• Years of climbing experience: significant for history of medial epicondylitis only (p&lt;0.0005)</li> <li>• Difficulty level climbing: non-significant (authors did not report a test statistic)</li> <li>• Years climbing at an elite level: non-significant</li> <li>• Gender: non-significant</li> </ul>
Schlegel <i>et al.</i> (2002) [20]	Cross-sectional	Adolescent, nationally-ranked sport climbers n=29	4	13	Sport climbing (elite level)	Climbers were divided into two groups: one with current finger pain, one asymptomatic.	<ul style="list-style-type: none"> <li>• Age: p&gt;0.05</li> <li>• Height: p&gt;0.05</li> <li>• Body weight: p&gt;0.05</li> <li>• Percentage of body fat: p&gt;0.05</li> <li>• Laxity score (0-9): p&gt;0.05</li> <li>• Start of regular climbing training (age): p&gt;0.05</li> </ul>

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Schlegel <i>et al.</i> (2002) <i>continued</i>		(sex distribution not reported) Ages 10-17 years					<ul style="list-style-type: none"> <li>• Increase in climbing difficulties (highest grade and increase in grade per year): <math>p&gt;0.05</math></li> <li>• Climbing training volume during the last season (hours/week): <math>p&gt;0.05</math></li> <li>• General physical training volume during the last season (hours/week): <math>p&gt;0.05</math></li> <li>• Climbing techniques such as position of the fingers while climbing on small grips: <math>p&gt;0.05</math></li> <li>• One finger climbing: <math>p&gt;0.05</math></li> <li>• Grip strength: <math>p&gt;0.05</math></li> <li>• Use of initial warm-up: <math>p&gt;0.05</math></li> </ul>
Schöffl <i>et al.</i> (2013) [21]	Cross-sectional	2012 World Cup Series competitors n=unknown (5 injury events, 40% male, 60% female) Ages not reported	4	7	Indoor competitive bouldering, sport climbing, and speed climbing	Injury events and medical incidences reported to the doctor in charge.	<ul style="list-style-type: none"> <li>• Sex: incidence rate = 0.54/1000h in males, 0.97/1000h in females</li> <li>• Climbing type: incidence rate = 0.29/1000h for lead climbing, 1.47/1000h for bouldering, zero for speed climbing</li> </ul>
Schöffl <i>et al.</i> (2013) [22]	Prospective cohort	Climbers at one indoor facility n=515, 337 visits (64% male, 36% female) Ages 8-80 years	2b	6	Indoor bouldering and sport climbing	Injuries requiring immediate medical attention, through either paramedic or doctor on site (ambulance was called)	<ul style="list-style-type: none"> <li>• Sex: Acute injury rates were equal in males and females (0.2/1000 hrs.)</li> </ul>

Study (year)	Study design	Study population	Oxford Level of Evidence	Downs & Black score (/32)	Type of climbing	Injury definition	Results of risk factor and prevention measure examination
Shahram <i>et al.</i> (2007) [12]	Cross-sectional	Male climbers from western provinces of Iran n=50 (100% male) Ages not reported	4	7	Sport climbing	Injury determined by clinical examination, (clinical signs: topical pain, weakness, tenderness, decreased range of motion, topical deformity, and physical tests)	<ul style="list-style-type: none"> <li>• Maximum climbing grade: p=0.000</li> <li>• Type of climbing: non-significant (authors did not report a test statistic)</li> </ul>
Tomczak <i>et al.</i> (1989) [23]	Cross-sectional	Rock climbers in Peru, U.S., U.K., Canada, Australia n=460 (95% male, 5% female) Mean age 31 years (range not reported)	4	7	All types of "rock climbing"	Injuries were classified as either fall injuries or overuse injuries. Location of each injury was determined.	<ul style="list-style-type: none"> <li>• Stretching prior to climbing: 'P' value of 0.9763</li> </ul>
Wright <i>et al.</i> (2001) [8]	Cross-sectional	Climbers participating at indoor facilities n=295 (sex not reported) Ages <20-35+ years	4	11	Indoor climbing (likely sport climbing and bouldering)	Overuse injury sustained indoors, defined in an introductory paragraph and reiterated verbally.	<ul style="list-style-type: none"> <li>• Sex: p=0.009</li> <li>• Preferred activity</li> <li>• Bouldering vs. top roping: p=0.001</li> <li>• Leading vs. top roping: p&gt;0.05</li> <li>• Bouldering/leading (together) vs. top roping: p&lt;0.0005</li> <li>• Lead grade: p&lt;0.0005</li> <li>• Bouldering: p&lt;0.0005</li> <li>• Age group: p=0.576</li> <li>• Years experience: p=0.006</li> <li>• Visits per annum: p=0.016</li> </ul>

## 1 Injury Incidence

2 Reported proportions and rates of injury in rock climbing are not easily compared due to varied  
 3 injury definitions, methodologies, reporting characteristics, and contexts of each study (Table 3). Backe *et*  
 4 *al.* estimated the injury incidence rate to be 4.2 injuries/1000 participation hours in climbing.[13] The  
 5 career incidence of injury ranges from 1.52 injuries/subject to 4.24 injuries/subject for a general  
 6 population of rock climbers.[23,24]

7 **Table 3. Reported injury incidence proportions or incidence rates for all reviewed studies**

Study (year)	Injury incidence proportion (IP) or incidence rate (IR) (95% Confidence Interval)
Tomczak <i>et al.</i> (1989) [23]	Career incidence proportion (IP): 428 injuries (409, 447)/100 participants
Limb (1995) [17]	Injury incidence rate (IR): 53.87 injuries (40.58, 70.12)/1 million visits
Paige <i>et al.</i> (1998) [1]	Not examined.
Rohrbough <i>et al.</i> (2000) [5]	Career IP: 300 injuries (250, 357)/100 participants
Wright <i>et al.</i> (2001) [8]	Not examined.
Carmeli <i>et al.</i> (2002) [14]	Not examined.
Schlegel <i>et al.</i> (2002) [20]	Not examined.
Logan <i>et al.</i> (2004) [9]	Career IP: 152 injuries (133, 172)/100 participants
Gerdes <i>et al.</i> (2006) [15]	Career IP: 131 injuries (126, 136)/100 participants (Authors allowed 3 injury reports maximum)
Josephsen <i>et al.</i> (2007) [2]	IP of outdoor bouldering injuries: 103 injuries (71, 146)/100 participants/year IP of indoor bouldering injuries: 127 injuries (85, 184)/100 participants/year
Shahram <i>et al.</i> (2007) [12]	Not examined.
Backe <i>et al.</i> (2008) [13]	IR: 4.2 injuries (3.61, 4.77)/1000 climbing hours (14 traumatic and 194 overuse injuries in 49,986 climbing hours)
Jones <i>et al.</i> (2008) [3]	IP: 137 injuries (121, 154)/100 participants/year
Nelson <i>et al.</i> (2009) [18]	Not examined.
Neuhof <i>et al.</i> (2011) [4]	IR: 0.2 injuries (0.02, 0.72)/1000 climbing hours (acute injury only)
Hasler <i>et al.</i> (2012) [16]	Not examined.
Pieber <i>et al.</i> (2012) [19]	Career IP: 194 injuries (175, 214)/100 participants
Schöffl <i>et al.</i> (2013) [21]	IR: 0.74 injuries (0.24, 1.73)/1000 competition hours -acute injury only
Schöffl <i>et al.</i> (2013) [22]	IR: 0.02 injuries (0.01, 0.03)/1000 climbing hours (acute injury only)

## 1 Risk Factors

2 The 19 studies introduced 35 possible risk factors or injury prevention measures, though 19 of  
3 these were examined uniquely in single studies.

4

### 5 Intrinsic Risk Factors

#### 6 Sex

7 Twelve studies examined sex as a potential risk factor for injury in sport climbing, bouldering, or  
8 both. Results were conflicting; six studies found no difference in injury risk between sexes,[2–5,16,22]  
9 while four found that males were at greater risk than females.[8,13,14,19] Schöffl *et al.* conversely found  
10 that the incidence rate of injury was 0.54 per 1000 competition hours for males, and 0.97 per 1000  
11 competition hours for females.[21] Nelson *et al.* found that females were at higher risk of sprain and  
12 strain injuries, while males were at higher risk of lacerations and fractures.[18] Study quality scores were  
13 similar for all studies, however Backe *et al.*, scored highest at 15/32 for their cross-sectional study, and  
14 had the second largest sample size with 355 participants.[13] Neuhof *et al.*, who, conversely, found no  
15 difference between sexes, had the largest sample size at 1962, and scored 12/32.[4]

#### 16 Age

17 Age was investigated as a possible risk factor in nine studies. Five reported that injury risk was not  
18 associated with age.[3,4,8,16,20] However, most of these studies covered a broad age range, with Downs  
19 and Black methodological quality scores between 11-13/32. Sample sizes ranged from 29-1962  
20 participants. Carmeli *et al.* reported finding significantly more hand and finger injuries ( $p < 0.05$ ) and a  
21 higher incidence of tendonitis in the long flexor tendons of the second and third fingers for those 19–34  
22 years versus those 9–18 years, though their study only included 19 participants.[14] However, Pieber *et*  
23 *al.*, whose sample size numbered 193, found that similarly, their two older age groups ( $29.5 \pm 1.7$  years and  
24  $39.7 \pm 5.6$  years) sustained significantly more injuries ( $p = 0.021$ ) than the younger climbers ( $23 \pm 2.4$   
25 years),[19] and Rohrbough *et al.* found that, of 42 climbers, those suffering from A2 pulley pain were  
26 significantly older ( $30.7 \pm 8.2$  years versus  $22.6 \pm 5.9$  years,  $p = 0.004$ ).[5] Conversely, Backe *et al.*, who

1 again scored highest on methodological quality at 15/32 and used a sample of 355 participants, found that  
2 the risk of re-injury increased for the adolescent age group, as opposed to older climbers ( $p=0.003$  for 20–  
3 45 year-olds, and  $p<0.001$  for +46-year-olds compared with <20-year-olds). However, their sample in this  
4 study was predominantly between 22 and 45 years.[13]

#### 5 *Years of Experience*

6 Total years of climbing experience were examined as a risk factor in seven studies. Three found the  
7 number of years of climbing participation to have no significant impact on the risk of injury,[2,3,13]  
8 while four found this factor to be a significant predictor of injury.[4,5,8,16] Wright *et al.* found higher  
9 injury rates in climbers with over 10 years of experience ( $p=0.006$ ), as did Hasler *et al.* ( $p=0.006$ ), though  
10 both of these studies analyzed prevalence only.[8,16] Similarly, Neuhof *et al.* found higher injury rates  
11 for climbers with over five years of experience ( $p<0.01$ ).[4] Finally, Rohrbough *et al.* found that history  
12 of medial epicondylitis increased with increasing experience ( $p<0.0005$ ), though these authors found no  
13 impact by experience on any other injuries.[5]

#### 14 *Difficulty (Skill) Level*

15 Eight studies investigated the highest difficulty level at which the subject could climb, a measure of  
16 skill level, as a risk factor for injury. Three studies found no significant impact on injury,[2,5,20] with  
17 study quality scores between 11-12/32 and sample sizes ranging from 29-152 participants. Five studies  
18 found a difference, though Gerdes *et al.* did not analyze this statistically.[3,4,8,12,15] Though the latter  
19 studies differed in their populations, all found that in general, participants that climbed at higher grades  
20 reported more injuries. Sample sizes varied between 201-1962 participants, though study quality scores,  
21 ranged from 7-12/32.

#### 22 *Body Mass Index (BMI)*

23 BMI was examined in three studies. Josephsen *et al.* and Neuhof *et al.* reported no significant  
24 difference in injury risk associated with this factor.[2,4] However, Backe *et al.*, who scored higher on  
25 methodological quality than either of the other studies (15/32 versus 12/32 for both of the former studies),

1 found that higher BMI was significantly associated with a higher risk of injury ( $p < 0.015$ ), and of re-injury  
2 ( $p = 0.121$ ).[13]

### 3 *Body Weight*

4 Only two studies examined weight as a risk factor, and neither found any significant association  
5 with injury.[2,20] However, because these studies examined different populations (Schlegel *et al.*'s study  
6 included only young, elite rock climbers, and Josephsen *et al.*'s, active boulderers), it is difficult to  
7 hypothesize the effect of body weight on injury.

### 8 *Grip Strength*

9 Grip strength in relation to injury risk has only been examined in two climbing-specific studies to  
10 date; Schlegel *et al.* (Downs and Black score: 13/32) measured grip strength at 90° of elbow flexion in 29  
11 climbers, and found that it did not significantly affect the risk of injury ( $p > 0.05$ ),[20] though Carmeli *et*  
12 *al.* (Downs and Black score: 11/32), who measured at 90° of shoulder flexion with a straight elbow in 19  
13 climbers, found a “mild to moderate correlation” ( $p < 0.05$ ).[14]

14

### 15 *Extrinsic Risk Factors*

#### 16 *Lead Climbing and Top roping*

17 Lead (sport) climbing was investigated in five studies.[1,4,8,12,15] Most of these articles compared  
18 it to top roping, though two also compared it to bouldering, and a third included bouldering, traditional  
19 climbing, and free soloing (free soloing is a type of climbing where no ropes, harnesses or any other  
20 protective gear are used, and therefore falls would likely be fatal). Four of these studies suggested that  
21 lead climbing was a risk factor for injury.[1,4,8,15] Though they did not conduct a statistical comparison,  
22 Schöffl *et al.*, who did not conduct a statistical comparison, noted the injury incidence rate for lead  
23 climbing to be 0.29 injuries per 1000 hours, versus 1.47 per 1000 hours for bouldering (and 0 for speed  
24 climbing, a third competitive discipline). Methodological scores ranged from 7-12/32 for these studies,  
25 though sample sizes were large, Gerdes *et al.*, for example, with 1887,[15] and Neuhof *et al.* with 1962  
26 participants.[4] Shahram *et al.* were the only authors who found that lead climbing was not associated

1 with injury, though this conclusion was based on prevalence proportions, as incidence and risk were not  
2 captured in their study.[12] Methodological quality was also low for this study (7/32), and the sample size  
3 comprised 50 climbers.

#### 4 *Climbing Volume*

5 The amount of time spent climbing (per week or per year) was examined in three studies.[4,13,20]  
6 Backe *et al.*, who scored highest on methodological quality at 15/32, found that the total climbing time  
7 each year did not have a significant effect on injury for their 355 participants, though the authors did  
8 control for exposure hours in their injury incidence rate (IR).[13] Schlegel *et al.*, whose study scored  
9 13/32, found the same results when examining injury and hours per week spent climbing, though they  
10 included only 29 participants.[20] Conversely, the study by Neuhof *et al.* found that climbing volume per  
11 week did significantly increase the risk of injury for their 1962 participants during both summer ( $p<0.01$ )  
12 and winter months ( $p<0.01$ ), though they did not indicate whether indoor climbing, outdoor climbing, or  
13 both were examined (Downs and Black score: 12/32).[4] Similarly, Jones *et al.* investigated the frequency  
14 of climbing (times per year) for each subject, and also found that as the frequency per year of outdoor  
15 (lead) sport climbing, indoor (lead) sport climbing, and bouldering increased, so did the incidence of  
16 overuse injury.[3]

#### 17 *Climbing Intensity Score (CIS)*

18 A climbing intensity score (CIS) was used in two studies to examine degree of exposure to  
19 “climbing stress” as a risk factor.[9,19] CIS scores, introduced by Logan *et al.*, and used again by Pieber  
20 *et al.*, indicate both climbing intensity and volume by multiplying the average grade of climbing by the  
21 mean number of climbing days per year.[9,19] Both studies found participants who scored higher in  
22 climbing intensity to be at a higher injury risk. Logan *et al.* (Downs and Black score: 10/32) compared an  
23 injury group to a non-injury group and found the mean CIS scores in the injury group to be significantly  
24 higher ( $p=0.01$ ).[9] Pieber *et al.* (Downs and Black score: 12/32) split CIS into tertiles (CIS 1:  $398\pm 232$   
25 points; CIS 2:  $1526\pm 461$  points; CIS 3:  $5088\pm 2701$  points) with 56 subjects per group, and found groups  
26 two and three to be significantly different from group one, which scored lower on the CIS ( $p<0.001$ ).[19]

### 1 *Indoor Versus Outdoor Climbing*

2 Two studies investigated outdoor climbing compared to indoor climbing as a predictor for injury.  
3 Josephsen *et al.* (Downs and Black score: 12/32), who examined bouldering specifically in 152  
4 participants, suggest a significantly higher risk of finger injuries outdoors, but a higher risk of fall-related  
5 injury indoors.[2] Gerdes *et al.* (Downs and Black score: 9/32), who examined sport climbing, traditional  
6 climbing, bouldering, and free soloing, observed an approximately even distribution of injuries indoors  
7 and outdoors in their 1887 participants.[15] However, traditional climbing is rarely performed indoors  
8 and free soloing is performed exclusively outdoors, thus introducing a potential bias. It is likely that  
9 outdoor injuries would be overrepresented for the purposes of this systematic review, since the focus here  
10 is on sport climbing and bouldering.

### 11 *Influence of Drugs/Alcohol*

12 Only two articles studied the influence of drugs or alcohol on climbing injury, and these yielded  
13 different results. Gerdes *et al.* (Downs and Black score: 9/32) found that substance use significantly  
14 increased the potential for injury in their 1887 participants, while Hasler *et al.* (Downs and Black score:  
15 13/32) found no significant increase in risk in their 113 subjects.[15,16]

### 16 *Other Risk Factors*

17 A number of different risk factors were examined uniquely in single studies (Table 2): wall  
18 height,[17] average boulder height,[2] maximum boulder height,[2] previous history of injury,[2] on-  
19 sighting (climbing a route for the first time),[16] self-reported readiness for risk,[16] lean body mass,[20]  
20 increase in climbing difficulty per year,[20] start age (of climbing),[20] performing regular one-finger  
21 climbing,[20] capsular thickening of finger joints,[20] radio-ulnar instability of finger joints,[20]  
22 Beighton score,[20] number of years climbing at the elite level,[5] handedness,[12] and climbing in a  
23 familiar versus new location.[15]

24

### 25 *Prevention Measures*

1 The self-reported use of a warm-up and different lengths of warm-up were investigated in three  
2 studies, and no significant difference in injury was found between groups.[2,17,23] Stretching prior to  
3 climbing was reported to be significantly associated with overuse injury by Tomczak *et al.* (Downs and  
4 Black score: 7/32) However, their claim that their “‘P’ value of 0.9763 [meant] that 97% of all people  
5 who reported stretching prior to climbing reported an overuse injury of some type” is incorrect.[23] It is  
6 possible that a value of 0.9763 is instead a correlation coefficient, in which case this would suggest a  
7 strong association between stretching and overuse injuries. Conversely, Josephsen *et al.*, who scored  
8 higher on methodological quality (12/32), found no significant difference in injury risk between those  
9 climbers who stretched versus those who did not. These authors also examined regular participation in  
10 yoga as a preventative measure and found the same results.[2] Imposing strict regulations regarding  
11 equipment use and instructor presence were not found to significantly decrease the risk of injury in sport  
12 climbing or bouldering, nor were the presence or number of safety mats used, nor the number of  
13 spotters.[2,17] Josephsen *et al.* also investigated the taping of fingers and wrists, taking glucosamine and  
14 other supplements, heating hands prior to climbing, taking time off to prevent injuries, the use of  
15 corticosteroid injections, and weight training as potential preventive measures. Of these strategies, only  
16 taping wrists and weight training were found to be significantly associated with a decreased rate of  
17 injury.[2]

18

## 19 DISCUSSION

20 In previous studies, older age, a higher number of years of climbing experience, higher climbing  
21 skill level, higher climbing intensity score (CIS), and lead climbing are risk factors. However, the  
22 reviewed studies differ in injury definitions, study populations, and methodological quality, resulting in  
23 variability in injury rates and making conclusions regarding risk factors difficult. Nevertheless,  
24 modifiable potential risk factors may be relevant for future interventions.

25 Many studies examining sport injury in general have identified age, sex, and BMI as significant  
26 risk factors for injury in youth, but there are conflicting results in the literature as to whether these

1 specific factors affect injury risk in rock climbers in this, or any other age group.[2,3,13,25–27] Results  
2 regarding sex as a risk factor for injury in climbing are conflicting. The majority of the studies examined  
3 samples that were predominantly male, and Wright *et al.*, who found a significantly higher risk of injury  
4 in males, failed to report sex distribution.[8] The studies that reported no difference between sexes  
5 included samples ranging from 59.9%-83.3% male.[2–5,16] It is therefore difficult to know the validity of  
6 these conclusions, as overall methodological quality was low.

7 Results suggest that older age may be a risk factor for injury in sport climbing and bouldering,  
8 though conclusions are difficult to draw, as reviewed studies used convenience samples with  
9 heterogeneous age groups. Authors have also suggested that there are differences in the types of injury  
10 sustained by younger and older climbers, such as epiphyseal fractures of the fingers from repeated stress  
11 on the bone in children and adolescents.[28] Based on this research, the International Climbing and  
12 Mountaineering Federation (UIAA) has set the minimum age for international bouldering competition  
13 participation to 16 years old. This guideline was established to minimize the risk of epiphyseal fractures,  
14 as bouldering training often involves dynamic movements that should be avoided in children whose bones  
15 have not yet matured sufficiently.[28] It would follow that if the types of injury differ between adults and  
16 children, the risk of injury may differ as well. Similar conclusions have been made previously with  
17 regards to resistance training in young children and adolescents, though past claims that such training is  
18 unsafe and poses a risk of injury are now being refuted. Current research indicates that age-appropriate  
19 resistance training can be safe.[29] Future studies are needed to explore this possibility in young climbers.  
20 An additional consideration when examining age as a risk factor is that multicollinearity may exist with  
21 factors such as years of experience and difficulty level. Analyses involving these individual factors must  
22 therefore be adjusted for age.

23 The literature suggests that increasing years of climbing experience may increase the risk of injury.  
24 More research is needed to confirm these findings and to explore whether this factor is associated with  
25 other variables (e.g., age, height, weight, skill level). The same is true for the highest difficulty or skill  
26 level at which individuals climb. A multitude of different rating scales were used to grade the technical

1 difficulty of climbs, as different countries and different disciplines often use different scales. However,  
2 the UIAA Medical Commission recently established a metric rating system into which all countries'  
3 scales can be converted, standardizing reporting for research purposes in particular.[30,31] With this  
4 scale, reporting will become more standardized, and it will become easier to compare studies and make  
5 conclusions about skill level as a risk factor.[31]

6        Though there is a paucity of valid research about BMI as a risk factor for injury in climbing, the  
7 results reported by Backe *et al.* that higher BMI was significantly associated with a higher risk of injury  
8 and re-injury appear to be valid, as this study was of higher methodological quality. As well, their study  
9 sample approached a normal population distribution for BMI, making their results more  
10 generalizable.[13] Previous research involving other sports has also indicated that BMI is a potentially  
11 modifiable risk factor.[26] As such, it may gain attention for injury prevention strategies in climbing.  
12 Similarly, body weight merits further investigation, though care must be taken when analyzing BMI and  
13 body weight together, considering multicollinearity between these two measures.

14        When compared to top roping (and in two cases bouldering), the examination of lead climbing  
15 suggests that it is a potential risk factor for injury. As a modifiable risk factor, limiting the amount of  
16 “leading” that a climber does may reduce injury.

17        Results are conflicting with regards to climbing volume as a predictor for injury in climbing. Backe  
18 *et al.* and Schlegel *et al.* did not find that higher climbing volumes increased the risk of injury.[13,20]  
19 Two studies, however, combined climbing volume with climbing grade to calculate CIS, both showing a  
20 significant correlation between higher CIS and injury. Neither study sample however, was representative  
21 of their population, and neither adequately adjusted for confounding.[9,19] While more research  
22 examining climbing volume and intensity is required, CIS may be a measure to use in future studies. Both  
23 climbing volume and CIS are potentially modifiable risk factors and knowing the healthy limit may aid in  
24 injury prevention.

25        Research involving general youth populations has shown that behaviours like alcohol consumption  
26 and smoking tobacco are risk factors for sport injury.[32] Although findings by Gerdes *et al.* and Hasler

1 *et al.* are conflicting, it follows that these behaviours would increase the risk of injury in youth  
2 climbers.[15,16] These behaviours are modifiable and therefore merit further investigation.

3 Finally, muscular strength has been suggested as a possible factor influencing musculoskeletal  
4 injury.[33] Results from the two studies examining this factor are difficult to ascertain conclusions from,  
5 but as low grip strength may be another modifiable risk factor, research is warranted in this area.

6 Few studies have investigated prevention strategies for climbing. Stretching is often used for injury  
7 prevention, though Josephsen *et al.*[2] found no association, and Tomczak *et al.*[23] suggested a positive  
8 relationship between climbing injury and the use of stretching. However, a high proportion of the subjects  
9 in Tomczak *et al.*'s study reported stretching prior to climbing (73%), and the association found by the  
10 authors does not necessarily imply causation. This is likely a spurious correlation.[23] Though there is  
11 presently no evidence that warming up affects injury risk in climbing and the use of stretching remains  
12 inconclusive, this may yet be an avenue for future research as these are both easily modifiable factors that  
13 many climbers perform nonetheless.

#### 14 **Limitations**

15 Several factors limit our ability to draw valid conclusions based on the data available for this  
16 systematic review, including the multidisciplinary nature of climbing, the multitude of injury definitions,  
17 injury rate reporting, and methodologies, and the heterogeneous nature of the study populations. The  
18 majority of studies were retrospective surveys and were therefore subject to the biases associated with  
19 cross-sectional studies. Recall bias and an overestimation of the most traumatic injuries may have  
20 resulted, as well as uncertainty of temporal relationships and causation. Selection bias is also a limitation  
21 of convenience samples, as injured climbers may not be included in the sample if they were not present  
22 during recruitment. Finally, publication bias may have influenced the results.

23

#### 24 **CONCLUSIONS & PERSPECTIVES**

1           Intrinsic and extrinsic risk factors for injury specific to sport climbing and bouldering have not  
2 previously been the subject of reviews. Twelve electronic databases and several other sources were  
3 searched systematically to examine risk factors and prevention strategies for injury in these disciplines,  
4 and to assess the methodological quality of existing studies. The injury incidence proportions and rates  
5 are inconsistent throughout the literature, emphasizing the need for standardized injury reporting in  
6 climbing research. Overall methodological quality of reviewed studies was low according to the Downs  
7 and Black Quality Index. However, several potential risk factors for injury in sport climbing and  
8 bouldering were highlighted, including age, increasing years of climbing experience, higher skill  
9 (difficulty) level, a high CIS, and lead climbing. Several potential risk factors are worth further  
10 investigation, namely those that are modifiable, such as BMI, taping, weight training, and the use of  
11 stretching. Results regarding injury prevention measures remain inconclusive. Future avenues for research  
12 in climbing should include previous injury, as it has been shown to be a significant predictor for  
13 subsequent injury in other sports,[6] as well as examining the use of correct climbing technique, and the  
14 growing issue of “climber’s back.” [34] As climbing continues to gain popularity, understanding the  
15 healthcare burden presented by this sport is essential. Developing injury prevention measures will reduce  
16 the strain on healthcare resources, and disseminating knowledge about the main types, mechanisms, and  
17 risk factors for injury will be important to reduce these injuries through awareness, for both climbers and  
18 healthcare providers. It will be important for future research to involve youth, such that young climbers,  
19 their parents, and coaches will be able to learn safe development and training for climbing.  
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## 1 REFERENCES

- 2 1 Paige TE, Fiore DC, Houston JD. Injury in traditional and sport rock climbing. *Wilderness*  
3 *Env Med* 1998;**9**:2–7.
- 4 2 Josephsen G, Shinneman S, Tamayo-Sarver J, *et al.* Injuries in bouldering: A prospective  
5 study. *Wilderness Environ Med* 2007;**18**:271–80. doi:10.1580/06-weme-or-071r1.1
- 6 3 Jones G, Asghar A, Llewellyn DJ. The epidemiology of rock-climbing injuries. *Br J*  
7 *Sports Med* 2008;**42**:773–  
8 [8.http://ezproxy.lib.ucalgary.ca:2048/login?url=http://search.ebscohost.com/login.aspx?dir](http://ezproxy.lib.ucalgary.ca:2048/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=rzh&AN=2010063114&site=ehost-live)  
9 [ect=true&db=rzh&AN=2010063114&site=ehost-live](http://ezproxy.lib.ucalgary.ca:2048/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=rzh&AN=2010063114&site=ehost-live)
- 10 4 Neuhof A, Hennig FF, Schöffl I, *et al.* Injury Risk Evaluation in Sport Climbing. *Int J*  
11 *Sports Med* 2011;**32**:794–800. doi:10.1055/s-0031-1279723
- 12 5 Rohrbough JT, Mudge MK, Schilling RC. Overuse injuries in the elite rock climber. *Med*  
13 *Sci Sports Exerc* 2000;**32**:1369–72. doi:10.1097/00005768-200008000-00002
- 14 6 Schöffl V, Hochholzer T, Winkelmann HP, *et al.* Pulley injuries in rock climbers.  
15 *Wilderness Env Med* 2003;**14**:94–100.
- 16 7 Shea KG, Shea OF, Meals R a. Manual demands and consequences of rock climbing. *J*  
17 *Hand Surg Am* 1992;**17**:200–5.<http://www.ncbi.nlm.nih.gov/pubmed/1564261>
- 18 8 Wright DM, Royle TJ, Marshall T. Indoor rock climbing: who gets injured? *Br J Sports*  
19 *Med* 2001;**35**:181–  
20 5.[http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1724320&tool=pmcentrez&](http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1724320&tool=pmcentrez&rendertype=abstract)  
21 [rendertype=abstract](http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1724320&tool=pmcentrez&rendertype=abstract)
- 22 9 Logan a J, Makwana N, Mason G, *et al.* Acute hand and wrist injuries in experienced rock  
23 climbers. *Br J Sports Med* 2004;**38**:545–8. doi:10.1136/bjism.2002.003558
- 24 10 Downs SH, Black N. The feasibility of creating a checklist for the assessment of the  
25 methodological quality both of randomised and non-randomised studies of health care  
26 interventions. *J Epidemiol Community Health* 1998;**52**:377–  
27 84.[http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1756728&tool=pmcentrez](http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1756728&tool=pmcentrez&rendertype=abstract)  
28 [&rendertype=abstract](http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1756728&tool=pmcentrez&rendertype=abstract)
- 29 11 OCEBM Levels of Evidence Working Group, Durieux N, Pasleau F, *et al.* The Oxford  
30 2011 Levels of Evidence. Group. 2011;**1**:5653.<http://www.cebm.net/index.aspx?o=1025>
- 31 12 Shahram A, Abdulmalek F, Reza R. A STUDY ON THE PREVALENCE OF  
32 MUSCULAR-SKELETON INJURIES OF ROCK CLIMBERS. *Education* 2007;**5**:1–7.

- 1 13 Backe S, Ericson L, Janson S, *et al.* Rock climbing injury rates and associated risk factors  
2 in a general climbing population. *Scand J Med Sci Sports* 2009;**19**:850–6.  
3 doi:10.1111/j.1600-0838.2008.00851.x
- 4 14 Carmeli E, Shuruk S, Sheklow SL, *et al.* Incidence of hand injuries in wall climbers: a  
5 comparison between adolescent adults and young adults. *Biol Sport* 2002;**19**:283–  
6 94.<http://articles.sirc.ca/search.cfm?id=S-901645>
- 7 15 Gerdes EM, Hafner JW, Aldag JC. Injury patterns and safety practices of rock climbers. *J*  
8 *Trauma* 2006;**61**:1517–25. doi:10.1097/01.ta.0000209402.40864.b2
- 9 16 Hasler RM, Bach P, Brodmann M, *et al.* A pilot case-control study of behavioral aspects  
10 and risk factors in Swiss climbers. *Eur J Emerg Med* 2012;**19**:73–6.  
11 doi:10.1097/MEJ.0b013e328348b460
- 12 17 Limb D. Injuries on British climbing walls. *Br J Sport Med* 1995;**29**:168–70.  
13 doi:10.1136/bjism.29.3.168
- 14 18 Nelson NG, McKenzie LB. Rock climbing injuries treated in emergency departments in  
15 the U.S., 1990–2007. *Am J Prev Med* 2009;**37**:195–200.  
16 doi:10.1016/j.amepre.2009.04.025
- 17 19 Pieber K, Angelmaier L, Csapo R, *et al.* Acute injuries and overuse syndromes in sport  
18 climbing and bouldering in Austria: a descriptive epidemiological study. *Wien Klin*  
19 *Wochenschr* 2012;**124**:357–62. doi:10.1007/s00508-012-0174-5
- 20 20 Schlegel C, Buechler U, Kriemler S, *et al.* Finger injuries of young elite rock climbers. ...  
21 *Zeitschrift für Sport ...* 2002;**50**:7–  
22 10.<http://cat.inist.fr/?aModele=afficheN&cpsidt=13638319> (accessed 8 Jun2014).
- 23 21 Schöffl VR, Burtscher E, Coscia F. INJURIES AND MEDICAL INCIDENCES DURING  
24 THE IFSC 2012 CLIMBING WORLD CUP SERIES. 2013;**17**:168–70.  
25 doi:10.5604/17342260.1081272
- 26 22 Schöffl V, Hoffmann G, Küpper T. Acute injury risk and severity in indoor climbing—a  
27 prospective analysis of 515,337 indoor climbing wall visits in 5 years. *Wilderness Environ*  
28 *Med* Published Online First:  
29 2013.<http://www.sciencedirect.com/science/article/pii/S1080603213000872> (accessed 31  
30 Jan2015).
- 31 23 Tomczak RL, Wilshire WM, Lane JW, *et al.* Injury patterns in rock climbers. *J Osteopath*  
32 *Sport Med* 1989;**3**:11–6.<http://articles.sirc.ca/search.cfm?id=239359>
- 33 24 Logan a J, Mason G, Dias J, *et al.* Can rock climbing lead to Dupuytren’s disease? *Br J*  
34 *Sports Med* 2005;**39**:639–44. doi:10.1136/bjism.2004.015792

- 1 25 Bijur PE, Trumble A, Harel Y, *et al.* Sports and recreation injuries in US children and  
 2 adolescents. *Arch Pediatr Adolesc Med* 1995;**149**:1009–16.  
 3 doi:10.1001/archpedi.1995.02170220075010
- 4 26 Rose MS, Emery CA, Meeuwisse WH. Sociodemographic predictors of sport injury in  
 5 adolescents. *Med Sci Sports Exerc* 2008;**40**:444–50. doi:10.1249/MSS.0b013e31815ce61a
- 6 27 Emery CA, Meeuwisse WH, McAllister JR. Survey of Sport Participation and Sport  
 7 Injury in Calgary and Area High Schools. *Injury* 2006;**16**:20–6.  
 8 doi:10.1097/01.jsm.0000184638.72075.b7
- 9 28 Hochholzer T, Schoffl VR. Epiphyseal fractures of the finger middle joints in young sport  
 10 climbers. *Wilderness Env Med* 2005;**16**:139–42.
- 11 29 Faigenbaum AD, Myer GD. Pediatric resistance training: Benefits, concerns, and program  
 12 design considerations. *Curr. Sports Med. Rep.* 2010;**9**:161–8.  
 13 doi:10.1249/JSR.0b013e3181de1214
- 14 30 Eng R, Van Pelt J, editors. Rating Systems. In: *Mountaineering: the freedom of the hills.*  
 15 Seattle, WA: : The Mountaineers Books
- 16 31 Schöffl V, Morrison A, Hefti U, *et al.* OFFICIAL STANDARDS OF THE UIAA  
 17 MEDICAL COMMISSION VOL : 17 The UIAA Medical Commission Injury  
 18 Classification for Mountaineering and Climbing Sports. *Wilderness Environ Med (Allen*  
 19 *Press Publ Serv Inc)* 2010;**41**:1–  
 20 8.<http://ezproxy.lib.ucalgary.ca:2048/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=rzh&AN=2010969549&site=ehost-live>  
 21
- 22 32 King MA, Pickett W, King AJC. Injury in Canadian youth: A secondary analysis of the  
 23 1993-94 health behaviour in school-aged children survey. *Can J Public Heal*  
 24 1998;**89**:397–  
 25 401.<http://ezproxy.lib.ucalgary.ca/login?url=http://search.proquest.com/docview/231979070?accountid=9838> LA - English  
 26
- 27 33 ‘Canadian Society for Exercise Physiology (CSEP)’. *Canadian Physical Activity, Fitness*  
 28 *and Lifestyle Approach Manual*. 3rd ed. Ottawa, Canada: 2003.
- 29 34 Forster R, Penka G, Bosl T, *et al.* Climber’s back--form and mobility of the thoracolumbar  
 30 spine leading to postural adaptations in male high ability rock climbers. *Int J Sports Med*  
 31 2009;**30**:53–9. doi:10.1055/s-2008-1038762

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1 **5 Multiple choice questions:**

2 Which is not a piece of injury prevention equipment used regularly while sport climbing or bouldering?

3 a) Ropes

4 b) Crash mats

5 c) Quickdraws

6 d) Helmets

7 e) Gloves

8 Which of the following is a modifiable potential risk factor for climbing injury?

9 a) Sex

10 b) Height

11 c) Body Mass Index (BMI)

12 d) Age

13 Which of the following has NOT been shown to be a potential risk factor for injury in the studies  
14 reviewed here?

15 a) Lead climbing

16 b) Top-roping

17 c) High climbing volume

18 d) High skill level

19 e) High Climbing Intensity Score

20 Which study design gives the least reliable evidence in a systematic review?

21 a) Case-control

22 b) Case-study

23 c) Randomized controlled trial

24 d) Cross-sectional

25 e) Quasi-experimental design

26 Which of the following is *not* true of the Climbing Intensity Score (CIS)?

- 1 a) CIS incorporates climbing volume (number of climbing days/year)
- 2 b) CIS incorporates climbing speed (metres/second)
- 3 c) CIS incorporates climbing intensity (average grade of climbing)
- 4 d) Higher CIS has been shown to be predictive of higher injury risk in two studies.

5

6 **Multiple choice answer key:**

7 Which is not a piece of injury prevention equipment used regularly while sport climbing or bouldering?

8 f) Ropes

9 g) Crash mats

10 h) Quickdraws

11 i) Helmets

12 **j) Gloves – gloves are not worn by climbers while sport climbing and bouldering, though some**  
13 **people choose to wear gloves if they are belaying.**

14 Which of the following is a modifiable potential risk factor for climbing injury?

15 e) Sex

16 f) Height

17 **g) Body Mass Index (BMI) – BMI is potentially modifiable, in that the weight of a person is**  
18 **variable and changeable, whereas the sex, age, and height are non-modifiable.**

19 h) Age

20 Which of the following has NOT been shown to be a potential risk factor for injury in the studies  
21 reviewed here?

22 f) Lead climbing

23 **g) Top-roping – top-roping has not been shown to be a risk factor for injury. It has sometimes**  
24 **been compared to lead-climbing, which *has* been shown in some studies to increase injury**  
25 **risk.**

26 h) High climbing volume

1 i) High skill level

2 j) High Climbing Intensity Score

3 Which study design gives the least reliable evidence in a systematic review?

4 f) Case-control

5 **g) Case-study – a case study is based on the description of a single case and therefore represents**  
6 **a weak level of evidence.**

7 h) Randomized controlled trial

8 i) Cross-sectional

9 j) Quasi-experimental design

10 Which of the following is *not* true of the Climbing Intensity Score (CIS)?

11 e) CIS incorporates climbing volume (number of climbing days/year)

12 **f) CIS incorporates climbing speed (metres/second) – The CIS does not incorporate speed. It**  
13 **represents both climbing intensity and volume by multiplying the average grade of climbing**  
14 **by the mean number of climbing days per year.**

15 g) CIS incorporates climbing intensity (average grade of climbing)

16 h) Higher CIS has been shown to be predictive of higher injury risk in two studies.

17