



## ORIGINAL RESEARCH

# Indoor Bouldering—A Prospective Injury Evaluation

Jonas Auer<sup>1</sup>; Volker R. Schöffl, MD, PHD, MHBA<sup>2</sup>; Leonard Achenbach, MD<sup>1</sup>; Rainer H. Meffert, MD, PhD<sup>1</sup>; Kai Fehske, MD, MA<sup>1</sup>

<sup>1</sup>Department of Trauma, Hand, Plastics and Reconstructive Surgery, University Clinics Würzburg, Würzburg, Germany; <sup>2</sup>Department of Sports Medicine—Sports Orthopedics, Klinikum Bamberg, Bamberg, Germany

**Introduction**—Bouldering has become a sport of growing interest, but little prospective evidence exists about injury proportions and patterns. The purpose of this study was to prospectively evaluate the cause of injuries sustained during indoor bouldering, proportion of affected body location, and injury severity.

**Methods**—Proportions and patterns of injury among German-speaking indoor boulderers were evaluated prospectively in an explorative cohort study. Participants completed a baseline questionnaire assessing anthropometric data and sport-specific potential preventive and risk factors, followed by monthly injury questionnaires including injury location and injury severity over a period of 12 mo.

**Results**—Out of 507 boulderers, 222 (44%) sustained 305 injuries. Of those, 78% (n=238) were classified as Union Internationale de Associations d'Alpinisme (UIAA) 1, 19% (n=57) as UIAA 2, and 3% (n=10) as UIAA 3. Injuries of the upper extremities accounted for 63% (n=191) of all injuries. Injuries of the lower extremities accounted for 23% (n=71) but were more often classified as UIAA $\geq$ 2 ( $P=0.0071$ ; odds ratio [OR] 2.23; 95% CI 1.23–4.04) and were more often caused by falling ( $P=0.0005$ ; OR 2.92; 95% CI 1.57–5.42) and jumping off the wall ( $P<0.0001$ ; OR 4.39; 95% CI 2.25–8.56) than injuries of other body locations. There was no statistically significant protective effect of the evaluated potential preventive measures. Participants who used heavily downturned climbing shoes had a higher risk of sustaining a UIAA  $\geq$ 2 injury ( $P=0.0034$ ; OR 2.58; 95% CI 1.34–4.95).

**Conclusions**—Injuries in indoor bouldering are common. Lower extremity injuries are associated with higher injury severity. Preventive measures need to be established to reduce bouldering injuries, especially during falls and landings.

*Keywords:* rock climbing, sports injuries, epidemiology, risk factors, injury severity

## Introduction

In its origins, bouldering was a method of training for alpine expeditions and summits. In the 20th century, bouldering evolved to an individual climbing subdiscipline, with written bouldering guidebooks and equipment. Regulation to conserve nature in popular bouldering areas became necessary, such as regulated parking, mandatory trails to the boulders, and protection zones where bouldering is prohibited. Around the turn of the millennium, a climbing boom started that led to the

appearance of indoor climbing gyms, often equipped with small bouldering rooms, in almost every major city in Germany. In recent years, more and more standalone indoor bouldering gyms have appeared in a vast number of German cities, leading to a considerable increase in active sports boulderers.<sup>1</sup> With more people practicing bouldering, an increase in bouldering-related injuries is to be expected.<sup>1–5</sup>

Bouldering can be defined as rock climbing without the use of a rope and harness on rock or artificial climbing walls of lower height.<sup>6</sup> The goal in bouldering is to solve a boulder problem by a sequence of movements, which usually have to be practiced several times until the athlete is able to put them together. A boulder problem consists of predefined holds that help to reach a defined target hold.<sup>2</sup> The majority of boulder problems have a height of 2.5 to 5 m, and to reduce the risk of injury from

Corresponding author: Kai Fehske, MD, MA, Department of Trauma, Hand, Plastics and Reconstructive Surgery, University Clinics Würzburg, Oberdürrbacher Str. 6, 97080 Würzburg, Germany; e-mail: [fehske\\_k@ukw.de](mailto:fehske_k@ukw.de).

Submitted for publication June 2020.

Accepted for publication February 2021.

falls from this height, it is common to use composite foam safety mats, either portable for outdoor utilization or permanently installed indoors.<sup>2,7</sup> Most boulderers use special climbing shoes to enable them to stand on small edges and use chalk to absorb moisture and prevent sweaty hands.<sup>8-11</sup> Climbing shoes have a special design and feature a varying degree of downturn (ie, a concavely shaped sole that places more pressure on the toes, which then are forced into a flexed position) and an asymmetric design that maximizes pressure on the hallux.<sup>8,10,12</sup>

There are many similarities between sport climbing and bouldering, but there are also some differences, which could affect injury pattern and prevalence.<sup>2</sup> Because of the low height of artificial indoor bouldering walls, bouldering problems tend to consist of fewer, but more difficult and strenuous, moves than comparable sport climbing routes.<sup>2</sup> Those moves are repeatedly practiced, which can lead to an increased number of overuse syndromes. In sport climbing, most falls are stopped by the rope and falls to the ground are rare. In bouldering, it is much more common to repeatedly fall to the ground or, in most cases, onto the safety mat on the ground; this is called a ground fall and can result in different injury patterns and possibly a different injury rate, especially of the lower extremities.<sup>1,2,12</sup> Additionally, injuries due to a collision with other falling athletes are also possible. Spotting, a boulder-specific safety measure, is practiced by bystanders, who try to redirect uncontrolled falls of the climber to enable safe landing, usually by rotating the falling climber into an upright position. This is typically done by grabbing the falling boulderer by the hips with both hands to slow their fall, enable landing on their feet, and direct them to a safer landing zone. This is to prevent injuries in general and in particular of the head, neck, and back. Because of these differences, the literature on rock climbing injuries cannot be unreservedly transferred to bouldering.<sup>2,12</sup>

The purpose of this study was to prospectively evaluate the cause of injuries sustained during indoor bouldering, the proportion of affected body location, and injury severity. Furthermore, the influence of potential preventive measures and risk factors on the injury rate was investigated.

## Methods

### STUDY DESIGN AND POPULATION

This was a prospective explorative cohort study in German-speaking boulderers. The study protocol was approved by the ethical review board of the Medical University of Würzburg.

Study participants were recruited between October 2017 and March 2018 via online media, print media, and in cooperation with bouldering gyms. The internet address to register for this study was published online and shared on Facebook by 11 German bouldering gyms and multiple private persons. In addition, the registration link was printed on flyers and distributed to 34 German bouldering gyms, and the survey was announced in a German climbing magazine.

Participants completed an online baseline questionnaire on anthropometric data, training habits, and potential preventive measures and risk factors. Follow-up questionnaires were sent monthly to the individual email address of each participant over the study period of 12 mo.

Inclusion criteria were an age of 18 y or older and activity in an indoor bouldering gym on a regular basis (ie, no one-time boulderers) during the study period. The exclusion criterion was failure to answer the questionnaire in the 12th month. Participants who did not answer emails in earlier months were not excluded, but we controlled for injuries sustained in the missing months in the following questionnaire.

### QUESTIONNAIRE DEVELOPMENT

The questionnaire was adapted from existing literature on rock climbing and sports injuries.<sup>2-4,8,13-17</sup> The questionnaire was developed and refined by clinical physicians in cooperation with active bouldering athletes. It was tested by active boulderers and revised based on their suggestions received until a consensus was found. A great value was set on comprehensibility for medical nonprofessionals and low time investment to accomplish high study participation.

### MEASUREMENTS AND OUTCOME MEASURES

The baseline questionnaire addressed anthropometric and sport-specific data, including sex, height, and weight; details on climbing shoes (size in comparison to the everyday shoe and degree of downturn, categorized as none, slight, medium, or heavy downturn); average weekly bouldering time; bouldering experience; and history of injury (“was there ever an injury that stopped you from training or doing your job for more than 24 h?”, “was there ever an injury that stopped you from training or doing your job for more than 10 d?”). Boulder-specific data such as duration of warm up (0 min, 0–10 min, 10–20 min, 20–30 min, or >30 min), spotting (not used, just used during risky moves, or used most of the time), and average weekly time practicing outdoor bouldering, indoor sport climbing, and outdoor sport climbing were assessed. Ultimately, the use/practice of cardio sports,

taping of the fingers, taping of other locations, slacklining or balance training, yoga, stretching, training with body weight or weights, warming up by doing easy boulder projects, warming up of fingers, campus board, pegboard, fingerboard, or grip trainers were addressed (yes or no).<sup>2,16</sup>

The monthly follow-up questionnaires assessed injuries sustained during bouldering in the past month. There were 3 possibilities: 1) occurrence of an injury, 2) no occurrence of an injury, and 3) still injured. Injuries were only included in this study if they led to an absence from work or training for more than 24 h; this was done to avoid reports of minimal trauma such as small abrasions or aching muscles. Body location (19 categories: head/face, neck/cervical spine, shoulder/clavicle, upper arm, elbow, forearm, wrist, hand/finger/thumb, chest, thoracic spine, trunk/abdomen, lumbar spine, pelvis/buttock, hip/groin, thigh, knee, lower leg, ankle, and foot/toe), severity (Union Internationale de Associations d'Alpinisme [UIAA] 1: mild injury or illness, no medical intervention necessary; 2: moderately severe injury or illness, not life threatening, outpatient therapy, heals without permanent damage; 3: major injury, not life threatening, hospitalization, surgical intervention, heals with or without permanent damage; 4: acute mortal danger, polytrauma, alive with permanent damage; 5: acute mortal danger, polytrauma, death; 6: immediate death), and cause of injury (bouldering, falling, jumping, training/stretching, caused by another boulderer, no acute trauma) were evaluated and classified using the Medical Commission of the UIAA MedCom Score.<sup>18</sup>

The primary outcome measure was the number of injuries caused by indoor bouldering during the study period, and the secondary outcome measure was injury severity.

## STATISTICAL ANALYSIS

Descriptive statistics are presented as mean±SD and categorical data as frequency counts (percentages). As statistical tools, the  $\chi^2$  test was used for nominally scaled data and Fisher's exact test to account for small sample size. The Kolmogorov-Smirnov test was used to test for standard distribution. The Mann-Whitney U test was used for ordinal or interval scaled data without standard distribution and logistic regression for categorical and continuous variables. Univariable logistic regression was used to calculate odds ratio (OR) and corresponding 95% CI. Multivariable logistic regression analysis was then performed on statistically significant independent variables to explore potential associations between potential preventive measures and risk factors and to calculate the adjusted OR and CI.  $P < 0.05$  was considered statistically

**Table 1.** Self-reported anthropometric data of indoor boulderers

	Male (n=285, 56%)	Female (n=221, 44%)	Total (n=506, 100%)
	Mean±SD	Mean±SD	Mean±SD
Age (y)	31±8	29±7	30±8
Height (cm)	181±7	169±6	175±9
Weight (kg)	75.2±10.7	61.0±7.2	69.0±10.8
BMI (kg·m <sup>-2</sup> )	23.1±2.9	21.4±2.2	22.4±2.7

significant. All analyses were performed using IBM SPSS statistics, version 22.0.

## Results

### ENROLLMENT AND POPULATION CHARACTERISTICS

A total of 697 participants completed the initial questionnaire. Of those, 17 were excluded because of incorrect contact data (nonexistent email addresses, n=14) and withdrawal of consent (n=3). The study period was completed by 507 participants, resulting in a drop-out rate of 25%. All 12 questionnaires were completed by 214 participants; the number of questionnaires completed was 10.5±1.9.

The study population consisted of 285 (56%) males, 221 (44%) females, and 1 unknown sex (0.2%). Men were slightly older ( $P=0.0089$ ; OR 1.03; 95% CI 1.01–1.06) and had a higher self-reported body mass index ( $P < 0.0001$ ; OR 1.46; 95% CI 1.32–1.61) than women (Table 1). The majority of all participants (59%; n=297) had sustained at least 1 injury before the study period that had caused more than 1 d absence from training or work; 55% (n=277) had an injury with a time loss of more than 10 d. A minority of 2% (n=8) practiced spotting most of the time, spotting during hard moves only was practiced by 53% (n=271), and 45% (n=228) never practiced spotting. Climbing shoes of a smaller size than regular shoes were used by 76% (n=385) of participants, 9% (n=46) used larger shoes, and 15% (n=73) used equally sized shoes. Heavily downturned climbing shoes were used by 12% (n=62), 63% (n=320) used moderately or slightly downturned shoes, and 25% (n=125) used climbing shoes without any downturn. The majority of participants (n=292, 58%) reported an average weekly boulder time of 2 to 5 h. In the study population, 22% (n=113) of boulderers had been bouldering regularly for more than 5 y and 23% (n=118) had been bouldering regularly for less than 1 y.

**Table 2.** Number of injuries during the study period by injury, location, and severity

Body location of injury	Injury severity			Total injuries n (%)
	UIAA 1 n (%)	UIAA 2 n (%)	UIAA 3 n (%)	
Head/Face	0	1 (0.3)	1 (0.3)	2 (0.7)
Neck/Cervical spine	5 (2)	4 (1)	0	9 (3)
Shoulder/Clavicle	36 (12)	10 (3)	2 (0.7)	48 (16)
Upper arm	12 (4)	0	0	12 (4)
Elbow	17 (6)	2 (0.7)	2 (0.7)	21 (7)
Forearm	7 (2)	2 (0.7)	0	9 (3)
Wrist	12 (4)	3 (1)	0	15 (5)
Hand/Finger/Thumb	77 (25)	9 (3)	0	86 (28)
Chest	7 (2)	0	0	7 (2)
Thoracic spine	1 (0.3)	1 (0.3)	0	2 (0.7)
Trunk/Abdomen	3 (1)	0	0	3 (1)
Lumbar spine	9 (3)	5 (2)	0	14 (5)
Pelvis/Buttock	2 (0.7)	1 (0.3)	0	3 (1)
Hip/Groin	1 (0.3)	0	0	1 (0.3)
Thigh	6 (2)	0	1 (0.3)	7 (2)
Knee	12 (4)	9 (3)	4 (1)	25 (8)
Lower leg	3 (1)	2 (0.7)	0	5 (2)
Ankle	15 (5)	7 (2)	0	22 (7)
Foot/Toe	10 (3)	1 (0.3)	0	11 (4)
Location unspecified	3 (1)	0	0	3 (1)
Total	238 (78)	57 (19)	10 (3)	305 (100)

### INJURY PROPORTION AND LOCATION

During the study period, 222 (44%) of the 507 participants sustained a total of 305 injuries. The highest individual number of injuries sustained during the study period was 5. The majority of injuries were classified UIAA 1 (78%; n=238), 19% (n=57) were UIAA 2, and 3% (n=10) were UIAA 3 (Table 2). There was no injury graded higher than UIAA 3.

The majority of injuries affected the upper limbs (shoulder/clavicle, upper arm, elbow, forearm, wrist, and hand/finger/thumb: n=191; 63%). However, injuries in that location were less often classified UIAA  $\geq 2$  than injuries in the other main location groups ( $P=0.0004$ ; OR 0.37; 95% CI 0.21–0.65). The most common injury location was fingers, hand, and thumb with 28% (n=86) of all injuries, followed by shoulder and clavicle with 16% (n=48). Injuries of the lower limbs (hip/groin, thigh, knee, lower leg, ankle, and foot/toe) accounted for 23% (n=71) of all injuries and were significantly more often classified UIAA  $\geq 2$  than injuries of other locations ( $P=0.0071$ ; OR 2.23; 95% CI 1.23–4.04).

The most common cause of acute injury was bouldering itself, such as performing a strenuous move, followed by falling and jumping off the wall (Table 3). Lower limb injuries were more often sustained due to falling ( $P=0.0005$ ; OR 2.92; 95% CI 1.57–5.42) and

jumping off the wall ( $P<0.0001$ ; OR 9.33; 95% CI 3.44–25.37) compared to injuries of other body locations. Injuries of the upper limbs happened more often without acute trauma ( $P<0.0001$ ; OR 4.39; 95% CI 2.25–8.56), and injuries of the ankle were more often caused by jumping off the wall ( $P<0.0001$ ; OR 17.12; 95% CI 6.04–48.53) than injuries of other locations. Nine of the 22 total injuries that occurred in the ankle region were caused by jumping. Just 1 (0.3%) injury was caused by another boulderer, who fell on the shoulder of a resting study participant.

### PREVENTIVE MEASURES AND RISK FACTORS

According to our findings, there was no significant difference in age ( $P=0.48$ ; OR 0.99; 95% CI 0.97–1.02), size ( $P=0.88$ ; OR 1.00; 95% CI 0.98–1.02), body weight ( $P=0.85$ ; OR 1.01; 95% CI 0.99–1.02), or body mass index ( $P=0.88$ ; OR 1.01; 95% CI 0.93–1.08) between participants who were affected by an injury and those who were not.

There was no protective effect of preventive measures or specific training for climbing (Tables 4 and 5). Warming up fingers, taping locations other than the fingers, and using a fingerboard seemed to affect the risk of sustaining an injury in a negative way. To investigate a possible explanation for these results, logistic regression

**Table 3.** Number of injuries sustained during the study period by location (sorted by main group) and cause of injury

	Head and neck n (%)	Upper limbs n (%)	Trunk n (%)	Lower limbs n (%)	Location unspecified n (%)	Total n (%)
Bouldering	1 (0.3)	55 (18)	8 (3)	19 (6)	0	83 (27)
Falling	6 (2)	23 (8)	4 (1)	23 (8)	0	56 (18)
Caused by another boulderer	0	1 (0.3)	0	0	0	1 (0.3)
Training/Stretching	0	3 (1)	2 (0.7)	1 (0.3)	0	6 (2)
No acute trauma	1 (0.3)	65 (21)	3 (1)	8 (3)	0	77 (25)
Jumping	1 (0.3)	3 (1)	2 (0.7)	14 (5)	0	20 (7)
Other	0	3 (1)	2 (0.7)	1 (0.3)	0	6 (2)
No information	2 (0.7)	38 (12)	8 (3)	5 (2)	3 (1)	56 (18)
Total	11 (4)	191 (63)	29 (10)	71 (23)	3 (1)	305 (100)

adjusting for potential confounders was used. Adjusting for bouldering experience, history of injury, and age showed no influence on warming up the fingers, but taping locations other than the fingers and using a fingerboard was no longer significant. There was no significant difference in the risk of sustaining a UIAA  $\geq 2$  injury between users and nonusers of preventive measures and specific training.

Spotting behavior ( $P=0.96$ ; OR 0.99; 95% CI 0.71–1.38), duration of a typical warm up ( $P=0.97$ ; OR 1.00; 95% CI 0.90–1.12), activity in other climbing sports ( $P=0.67$ ; OR 1.00; 95% CI 0.98–1.02), and size of climbing shoes used ( $P=0.28$ ; OR 0.92; 95% CI 0.80–1.07) had no influence on injury rate. Intensity of downturn in climbing shoes did not affect the general risk of sustaining an injury ( $P=0.16$ ; OR 1.14; 95% CI 0.95–1.36), but participants who used heavily downturned climbing shoes had a higher risk of sustaining an injury classified as UIAA  $\geq 2$  ( $n=5071$   $P=0.0034$ ; OR 2.58; 95% CI 1.34–4.95), despite adjusting for bouldering experience, history of injury, and age. Bouldering experience did not affect general rate of injury ( $P=0.40$ ; OR 1.25; 95% CI 0.74–2.25) or rate of injury UIAA  $\geq 2$  ( $P=0.59$ ; OR 1.04; 95% CI 0.90–1.22), but participants who had practiced bouldering on a regular basis for less than 1 y were more often affected by injuries of the lower extremities ( $n=507$ ;  $P=0.027$ ; OR 1.85; 95% CI 1.07–3.21). The risk of sustaining an injury was higher among those who had a history of injury ( $n=504$ ;  $P=0.020$ ; OR 1.54; 95% CI 1.07–2.21). Adjusting for bouldering experience and age had no influence on this result. Of the participants who had sustained at least 1 injury that caused more than 1 d absence from training or work prior to the study period, 48% ( $n=143$ ) were injured during the study period, compared to 38% ( $n=78$ ) of those without a history of injury. Examining only injuries of severity UIAA  $\geq 2$ , no statistically significant difference was found.

## Discussion

A considerable proportion of boulderers (44%) reported at least 1 injury during the assessed 12 mo. The majority of injuries were of minor severity. This extends findings from an prospective cohort study that found similar results, with an injury rate of 42% during a 12-mo period in a mixed population of indoor climbers and indoor boulderers; however, only injuries of the upper extremities were included, and an injury rate of 58% was found in the subgroup of boulderers.<sup>14</sup> Another prospective cohort study reported an alarming rate of injury, with 17 injuries caused by bouldering and 11 injuries caused by falling in 22 indoor boulderers within 12 mo, but these numbers could be biased by a high dropout rate and a small sample size.<sup>2</sup> In a retrospective study including a collection of mixed climbing styles, an injury rate of 50% within 12 mo was reported.<sup>17</sup>

Data on injury location are inconsistent in sport climbing. Some studies focus on upper extremity injury, excluding injury of the lower extremities, whereas others focus on a single injury mechanism.<sup>8,14,19,20</sup> A prospective single-center study in a German climbing area, including 836 patients with climbing injuries, reported a 6% rate of injuries of the lower extremities.<sup>21</sup> Three analyses of rock climbing injury treated in US emergency rooms reported that most acute climbing injuries concern the lower extremities.<sup>5,13,22</sup> It is worth mentioning that those 3 analyses included only acute injuries, no injuries due to overstrain, and were not limited to indoor bouldering. In our study population, the most common injury location was the upper extremity, especially hand, finger, and thumb, as well as shoulder and clavicle. Less than a quarter of all injuries affected the lower limbs, but those injuries were more severe and more likely to be caused by falling. These results suggest that further research is needed to determine methods for reducing the severity of lower limb injury and ways to improve falling and jumping safety.<sup>1,8</sup>

**Table 4.** Effect of preventive measures on injury rate

	Total sample size: Preventive measure used		Injured participants (injury rate): Preventive measure used		Comparison of injury rate by usage of training method	
	Yes n (%)	No n (%)	Yes n (%)	No n (%)	P	OR (CI)
Warming up of fingers	268 (53)	239 (47)	130 (49)	92 (39)	0.023	1.51 (1.06–2.14)
Warming up with easy boulder problems	478 (94)	29 (6)	211 (44)	11 (38)	0.51	1.29 (0.60–2.80)
Training with bodyweight or weights	269 (53)	238 (47)	125 (47)	97 (41)	0.20	1.26 (0.89–1.80)
Stretching	361 (71)	146 (29)	164 (45)	58 (40)	0.24	1.26 (0.85–1.87)
Yoga	122 (24)	385 (76)	54 (44)	168 (44)	0.90	1.03 (0.68–1.55)
Slacklining, balance training	96 (19)	411 (81)	41 (43)	181 (44)	0.81	0.95 (0.61–1.48)
Taping of the fingers	102 (20)	405 (80)	47 (46)	175 (43)	0.60	1.12 (0.73–1.74)
Taping of other locations	39 (8)	468 (92)	23 (59)	199 (43)	0.047	1.94 (1.00–3.77)
Cardio sports	257 (51)	250 (49)	105 (41)	117 (47)	0.18	0.79 (0.55–1.12)

Total sample size n=507; injured participants n=222; injury rate refers to  $\geq 1$  injury sustained during study period.

Most acute injuries were caused by bouldering itself, followed by falling. Injury caused by another boulderer is rare, which seems to be consistent with the literature.<sup>2</sup> Injury without acute trauma was sustained by 15% of our study population during the study period. Most of these injuries can be classified as overuse injuries, and most affected the upper extremities. The literature is inconsistent in terms of overuse injuries and rates differ greatly. A retrospective study reported a 44% career risk of sustaining an overuse injury, and another retrospective study investigating chronic climbing injuries reported a rate of 58% within 6 mo.<sup>23,24</sup>

In 1 previous study, a protective effect of weight training and wrist taping was found.<sup>2</sup> In our study population, use of the investigated preventive measures did not reduce the injury rate, a finding also supported by a study on youth rock climbers.<sup>25</sup> Warming up the fingers seemed to increase the risk of injury, but it is likely that this effect was caused by a confounder that we did not take into account within this study (eg, level of bouldering skill or compensation of risky behavior and frequency of use were not assessed).<sup>25</sup>

Spotting seems to be less common in German indoor bouldering facilities than in the indoor bouldering cohort of a North American prospective study.<sup>2</sup> Spotting behavior had no impact on injury rate in this indoor bouldering study population, but these results should definitively not be transferred to outdoor bouldering. There is literature on orthopedic changes and nerve compression syndromes caused by tight and unnaturally shaped climbing shoes that enable standing on small edges but force the foot and toes into an unnatural position.<sup>8–10,26</sup> Previous literature suggests a connection between choice of climbing shoe and the rate of injury in sports climbing.<sup>8,9,26</sup> Although there was no effect on the injury rate in our study population, there was an

effect on injury severity. Thus, usage of heavily downturned climbing shoes might lead to a higher risk of severe injury. It may be beneficial to reduce usage of heavily downturned climbing shoes by using a second pair of loose shoes for training, as suggested by the literature on foot injuries in rock climbers.<sup>8</sup>

Beginners had a higher risk of injury of the lower extremities; thus, courses for beginners should teach safer falling techniques. The risk of injury was increased among those who had a history of injury, which is consistent with the literature on climbing injuries.<sup>14,15</sup> This finding is not limited to climbing-related sports but is common in other sports as well (eg, football and CrossFit).<sup>27,28</sup> The reason for a high reinjury rate in bouldering may be in the nature of the sport: hard moves at the athlete's maximum physical capacity, which are practiced repeatedly.

## LIMITATIONS

Using an online questionnaire without any medical validation creates several limitations.

Because this study involves self-reported data, the results should be interpreted with caution. It is possible that participants provided false information, intentionally or unintentionally. Although the dropout rate was only about a quarter of the original participants, this may have influenced the results in either direction. There could be a reporting bias, meaning that those who experienced an injury could have been more likely to complete the follow-up, which could result in over-reporting of the injury rate. Possible fatalities could not be detected in this study design, and fatalities would have been lost to follow-up. It is also possible that nonfatal injuries were lost to follow-up (eg, decreased willingness to participate in a study when bouldering

**Table 5.** Effect of training methods on injury rate

	Total sample size:		Injured participants		Comparison of injury rate	
	Training method used		(injury rate):		by usage of training method	
	Yes n (%)	No n (%)	Yes n (%)	No n (%)	P	OR (CI)
Campus board	109 (22)	398 (78)	49 (45)	173 (44)	0.78	1.06 (0.69–1.63)
Pegboard	32 (6)	475 (94)	18 (56)	204 (43)	0.14	1.71 (0.83–3.52)
Fingerboard	105 (21)	402 (79)	56 (53)	166 (41)	0.027	1.63 (1.06–2.50)
Grip trainers	91 (18)	416 (82)	48 (53)	174 (42)	0.057	1.55 (0.99–2.45)
No use of a training method	262 (52)	245 (48)	107 (41)	115 (47)	0.17	0.78 (0.55–1.11)

Total sample size n=507; injured participants n=222; injury rate refers to  $\geq 1$  injury sustained during study period; training method refers to specific training method for climbing.

was no longer possible because of injury). This could lead to underreporting of the injury rate. Other results of this study, such as identified risk factors, may also have been influenced by participants lost to follow-up. There was no validation and examination of the sustained injury by a medical professional during the study period. The reported injuries were not always clear and easy to translate into medical terms, and the severity of injury was not always clearly assignable to 1 category of the UIAA Injury and Illness Severity Classification. This could result in both overreporting and underreporting of injury severity. Weekly bouldering time was assessed only in the baseline questionnaire and not in the monthly follow-up questionnaires. It is likely that during the duration of the study the real weekly bouldering time differs considerably from the initially stated time. This is why we did not state an injury rate per time. Future studies should survey the actual time spent bouldering to calculate injury risk per 1000 hours of bouldering, as the UIAA recommends.<sup>18</sup> Usage of preventive measures, specific training, and so on was surveyed only at the beginning of the study, and frequency of use was not assessed. There was no possibility to adapt changed training habits. This study did not examine any possible comorbidities that might act as confounders. We also did not investigate the difficulty of bouldering problems that caused an injury or the most difficult climbing problem that a participant was able to perform. We refrained from investigating these data because there is no comparable common grading system in most German indoor bouldering facilities. We used “bouldering experience” as a surrogate measure of bouldering skill to calculate an adjusted OR, but this variable probably does not fully correlate with bouldering skill. Due to the study design, injuries of 1-time boulderers and athletes who do not regularly boulder were not investigated. The size of climbing shoes differs between brands and is not always comparable. Furthermore, the perception of downturn and

asymmetry is highly subjective. The height of fall was not consistently specified; therefore, we cannot state a correlation between injury and height of fall. The geographic limitation of this study to German-speaking participants could influence the injury rate because of different safety standards of indoor bouldering gyms.

## Conclusions

Injuries in indoor bouldering are common. Lower extremity injuries are associated with higher injury severity. Commonly used preventive measures seem to be ineffective in reducing the rate and severity of injury. The choice of climbing shoes seems to affect severity of lower limb injury. Preventive measures need to be established to reduce bouldering injuries, especially during falls and landings.

Author Contributions: Study concept and design (JA, VS, LA, RM, KF), acquisition of the data (JA), analysis of the data (JA), drafting of the manuscript (JA, KF, VS), critical revision of the manuscript (VS, LA, RM, KF), approval of final manuscript (JA, VS, LA, RM, KF).

Financial/Material Support: None.

Disclosures: None.

## References

1. Lutter C, Tischer T, Cooper C, Frank L, Hotfiel T, Lenz R, et al. Mechanisms of acute knee injuries in bouldering and rock climbing athletes. *Am J Sports Med.* 2020;48(3):730–8.
2. Josephsen G, Shinneman S, Tamayo-Sarver J, Josephsen K, Boulware D, Hunt M, et al. Injuries in bouldering: a prospective study. *Wilderness Environ Med.* 2007;18(4):271–80.
3. Pieber K, Angelmaier L, Csapo R, Herceg M. Acute injuries and overuse syndromes in sport climbing and bouldering in Austria: a descriptive epidemiological study. *Wien Klin Wochenschr.* 2012;124(11–12):357–62.
4. Schöffl VR, Hoffmann G, Küpper T. Acute injury risk and severity in indoor climbing—a prospective analysis of 515,

- 337 indoor climbing wall visits in 5 years. *Wilderness Environ Med.* 2013;24(3):187–94.
5. Buzzacott P, Schöffl I, Chimiak J, Schöffl V. Rock climbing injuries treated in US emergency departments, 2008–2016. *Wilderness Environ Med.* 2019;30(2):121–8.
  6. Jones G, Schöffl V, Johnson MI. Incidence, diagnosis, and management of injury in sport climbing and bouldering: a critical review. *Curr Sports Med Rep.* 2018;17(11):396–401.
  7. Gilchrist P, Osborn G. Risk and lifestyle sports: the case of bouldering. *Entertainment and Sports Law Journal.* 2017;15(1):5.
  8. Schöffl V, Küpper T. Feet injuries in rock climbers. *World J Orthop.* 2013;4(4):218–28.
  9. Peters P. Nerve compression syndromes in sport climbers. *Int J Sports Med.* 2001;22(8):611–7.
  10. van der Putten EP, Snijder CJ. Shoe design for prevention of injuries in sport climbing. *Appl Ergon.* 2001;32(4):379–87.
  11. Saul D, Steinmetz G, Lehmann W, Schilling AF. Determinants for success in climbing: a systematic review. *J Exerc Sci Fit.* 2019;17(3):91–100.
  12. Schweizer A. Sport climbing from a medical point of view. *Swiss Med Wkly.* 2012;142:w13688.
  13. Pierpoint L, Klein M, Comstock RD. Epidemiology of rock climbing injuries treated in United States emergency departments, 2006–2015. *Br J Sports Med.* 2017;51(4):374–5.
  14. van Middelkoop M, Bruens ML, Coert JH, Selles RW, Verhagen E, Bierma-Zeinstra SMA, et al. Incidence and risk factors for upper extremity climbing injuries in indoor climbers. *Int J Sports Med.* 2015;36(10):837–42.
  15. Jones G, Llewellyn D, Johnson MI. Previous injury as a risk factor for reinjury in rock climbing: a secondary analysis of data from a retrospective cross-sectional cohort survey of active rock climbers. *BMJ Open Sport Exerc Med.* 2015;1(1):bmjsem-2015-000031.
  16. Woollings KY, McKay CD, Emery CA. Risk factors for injury in sport climbing and bouldering: a systematic review of the literature. *Br J Sports Med.* 2015;49(17):1094–9.
  17. Jones G, Asghar A, Llewellyn DJ. The epidemiology of rock-climbing injuries. *Br J Sports Med.* 2008;42(9):773–8.
  18. Schöffl V, Morrison A, Hefti U, Ullrich S, Küpper T. The UIAA Medical Commission injury classification for mountaineering and climbing sports. *Wilderness Environ Med.* 2011;22(1):46–51.
  19. Logan AJ, Makwana N, Mason G, Dias J. Acute hand and wrist injuries in experienced rock climbers. *Br J Sports Med.* 2004;38(5):545–8.
  20. Schöffl V, Lutter C, Popp D. The “heel hook”—a climbing-specific technique to injure the leg. *Wilderness Environ Med.* 2016;27(2):294–301.
  21. Schöffl V, Popp D, Küpper T, Schöffl I. Injury trends in rock climbers: evaluation of a case series of 911 injuries between 2009 and 2012. *Wilderness Environ Med.* 2015;26(1):62–7.
  22. Nelson NG, McKenzie LB. Rock climbing injuries treated in emergency departments in the U.S., 1990–2007. *Am J Prev Med.* 2009;37(3):195–200.
  23. Wright DM, Royle TJ, Marshall T. Indoor rock climbing: who gets injured? *Br J Sports Med.* 2001;35(3):181–5.
  24. Grønhaug G. Self-reported chronic injuries in climbing: who gets injured when? *BMJ Open Sport Exerc Med.* 2018;4(1):e000406.
  25. Woollings KY, McKay CD, Kang J, Meeuwisse WH, Emery CA. Incidence, mechanism and risk factors for injury in youth rock climbers. *Br J Sports Med.* 2015;49(1):44–50.
  26. Killian RB, Nishimoto GS, Page JC. Foot and ankle injuries related to rock climbing. The role of footwear. *J Am Podiatr Med Assoc.* 1998;88(8):365–74.
  27. Hägglund M, Waldén M, Ekstrand J. Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. *Br J Sports Med.* 2006;40(9):767–72.
  28. da Costa TS, Louzada CTN, Miyashita GK, da Silva PHJ, Sungaila HYF, Lara PHS, et al. CrossFit: injury prevalence and main risk factors. *Clinics (Sao Paulo).* 2019;74:e1402.