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Risk Factors and Injury Prevention Among Female Rock Climbers

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BACKGROUND: Female climbers are underrepresented in the literature on rock climbing injuries despite their increasing participation in the sport and higher risk for certain health conditions, especially those related to menstrual dysfunction and bone mineral density. We aimed to investigate potential risk factors for injury as well as possible protective behaviors among recreational female climbers.
METHODS: We designed and distributed a 31-question survey on health and demographic characteristics, rock-climbing experience, training behaviors, and injury in the past 12 months. The survey was distributed via 6 online rock-climbing forums and 2 physical locations at rock-climbing gyms in Baltimore County, MD. Female climbers ≥18 years were invited to participate. Analyses were conducted to compare basic demographic characteristics of climbers with and without injury in the past year as well as to investigate associations between injury and potential risk factors.
RESULTS: Nine hundred ninety-seven female climbers completed the survey. In bivariate analysis, warming up with activities other than climbing was significantly associated with injury in the past year compared to warming up with climbing only. After adjusting for hours per week climbing and relevant health conditions and training behaviors, climbers who participated in bouldering were more likely to have experienced injury in the past year (odds ratio [OR] = 1.69; 95% confidence interval [CI] 1.10–2.64; $p = 0.018$), whereas climbers who regularly participated in other sports were less likely to have experienced injury (OR = 0.65; 95% CI 0.48–0.87; $p = 0.005$). History of an eating disorder was associated with injury when adjusting for age, diagnosis of amenorrhea, and diagnosis of another physical health condition (OR = 1.53; 95% CI 1.02–2.33; $p = 0.043$).
CONCLUSION: Cross-training and climbing-specific warm-up routines may be protective against injury among female climbers, but bouldering may have a higher risk of injury compared to other climbing disciplines. Clinicians should be aware that climbers with eating disorders may be at particularly high injury risk. Continued investigation into safe training practices is essential to ensure the long-term health and performance of recreational female climbers.

INTRODUCTION

Rock climbing has exploded in popularity over the early 21st century and became an Olympic sport in 2020. Once exclusively practiced outdoors and considered an activity reserved for outdoor extremists, it is now a thriving sport among the general public and commonly practiced indoors at commercial climbing gyms. In 2019, the International Federation of Sport Climbing estimated that there were 44.5 million climbers worldwide.[1] In the United States alone, the number of climbing gyms grew from 353 to 622 between 2014 and 2023, an increase of 76% in a mere decade.[2,3] The most popular disciplines of rock climbing, which can be practiced both indoors and outdoors, are bouldering, top-roping, and sport or lead climbing (Figure 1).

Rock climbing injury incidence and severity vary based on the climbing discipline but it is a relatively safe sport, especially when practiced indoors, with a rate of injury lower than or comparable to other popular sports.[4–12] Backe et al.[4] found an incidence of 4.2 injuries per 1,000 climbing hours in a general climbing population, accounting for both traumatic and overuse types of injury. However, climbers experience unique, sport-specific injuries that warrant closer investigation into their epidemiology, prevention, and management.[9] Upper extremity injuries, especially in the hands, fingers, and wrists, are the most

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common and often due to chronic overuse and strain.[4,7,13–18] Injuries of the lower extremities are typically more likely to be acute, traumatic injuries from uncontrolled falls and more often require surgical intervention.[4,13,15,16,19–24]

Prior studies have attempted to analyze potential risk factors for injury, often with conflicting results. A systematic review of the literature on risk factors for injury in sport or lead climbing and bouldering by Woollings et al.[8] demonstrated that age, increasing years of climbing experience, climbing level, climbing intensity, and participation in lead climbing were most convincingly associated with a higher risk of injury, even while many of the studies comprising their review came to conclusions different from the authors'. A separate review focusing on the bouldering discipline concluded that body mass index (BMI) and performing a warm-up were not associated with risk of overuse injury, and that strength and conditioning may be effective interventions in preventing climbing injury.[7] Behaviors such as hang board training and sport specialization have also been investigated in youth climbers, who have unique injury profiles such as increased incidence of physeal overuse injuries, but not in adult female climbers.[25]

The growth of research in climbing has paralleled the sport's rise in popularity; however, female climbers are substantially underrepresented in the current literature despite making up 42% of all indoor climbers in the United States and 33% of those who climb outdoors.[26] While many studies collect gender or sex as demographic information, women make up a scant proportion of the total sample size.[7] To the best of our knowledge, only one group has examined sex-specific risk factors for injury. Grønhaug et al.[27] found a high prevalence of amenorrhea (15.8%) and eating disorders (32.4%) among elite female climbers as well as a high prevalence of injury among those with amenorrhea (55.6%) and a doubled odds ratio for injury among those with an eating disorder. While this study has limited generalizability because of the sample population, their findings are consistent with the well-characterized female athlete triad, the combination of menstrual dysfunction, low energy availability with or without an eating disorder, and low bone mineral density (BMD) that is relatively common among young women in sports.[28] These findings strongly suggest that a more comprehensive exploration of sex-specific risk factors and their potential influence on injury rates in the general population of recreational female climbers is needed.

Further, many of the studies on the epidemiology of climbing injuries and risk factors are more than 10 years old and may therefore be outdated, given the noticeable changes in climbing styles that have accompanied the popularization of the sport. Indoor climbing routes are on increasingly more overhung walls and artificial climbing holds allow for more dynamic, acrobatic movements compared to climbing on natural rock, in part to make the sport more entertaining for spectatorship.[29–31] This evolution could very feasibly manifest in changes in the types of injuries climbers most commonly experience today.[27,32] Much of the research on climbing has also been conducted in Europe, and there could be regional differences in route-setting styles that mirror the natural rock formations found in different parts of the world.

Therefore, the aim of this study was to investigate potential risk factors for injury, especially sex-specific risk factors such as menstrual dysfunction and low BMD, as well as possible protective behaviors in female climbers through a comprehensive survey study. The secondary aim was to contribute an updated characterization of the most common sites and types of injuries that female climbers experience.

Figure 1.
Popular disciplines of rock climbing

A. Bouldering
B. Top-roping
C. Sport climbing

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METHODS

Study design

This study was deemed exempt by our institutional review board. A 31-question survey was designed in Qualtrics (Qualtrics, Provo, UT) to collect information on health and demographic characteristics, rock-climbing experience, training behaviors, and incidences of injury in the past 12 months. The survey was distributed using an anonymous link via 6 online rock-climbing forums across MountainProject.com, CascadeClimbers .com, Reddit.com, and Facebook.com as well as in two physical locations at rock-climbing gyms in Baltimore County, Maryland. Female climbers ages 18 years and older were invited to participate. The survey was open for responses between June 15 and July 1, 2024.

Variables and Outcome

Health and demographic information collected included gender identity; sex assigned at birth; age; height; weight; and history of physical and mental health conditions including menstrual dysfunction, eating disorders, and low BMD. Climbing-related information collected included climbing experience, type and setting of climbing participated in, and warm-up and training habits such as hours spent climbing per week, use of a hang board, and participation in other sports. Finally, participants were asked to report any climbing-related injuries experienced in the past 12 months.

Statistical Analysis

Bivariate analyses were conducted to compare basic demographic characteristics of climbers with and without injury in the past year as well as to investigate associations between injury and potential risk factors. Chi-square tests were used for categorical variables, and t-tests were used for continuous variables. Multivariate logistic regressions were conducted as secondary analysis to further investigate significant associations while controlling for possible confounders. The threshold for statistical significance was set at $p < 0.05$. All statistical analyses were conducted in R (version 4.3.2)[33] using RStudio (version 2023.12.1+402).[34] The packages tidyverse, ggplot2, ggrepel, table1, DiagrammeR, DiagrammeRsvg, and rsvg packages were used to generate figures and tables.

RESULTS

A total of 1,112 survey responses were obtained during the data collection period. Of these, 115 were excluded on the basis of being incomplete (n = 86), inappropriate age (n = 7), unsure gender identity (n = 1), or male sex at birth (n = 21). The final study sample comprised 997 female climbers aged 18 years or older (Figure 2).

We were unable to calculate a response rate because it was impossible to know how many potential participants saw the recruitment materials in-person and not all online forums provided view statistics for the online postings.

Nine hundred fifty-five (95.8%) participants reported their gender identity as female and 42 (4.2%) as a non-binary gender. Athletes came from 35 countries (Figure 3), the most common being the United States (n = 665), Canada (n = 74), and the United Kingdom (n = 63).

The majority of participants climbed between 3 and 6 hours per week (Figure 4A) and had climbed a highest grade between V3 and V5, according to the Hueco grading scale, or approximately 5.11 to 5.12, according to the Yosemite Decimal System, within 3 attempts (Figure 4B). Bouldering was the most popular climbing discipline, followed by top-roping, sport or lead climbing, and traditional climbing (Figure 4C). Most athletes (n = 787; 78.9%) had participated in more than one type of climbing in the past 12 months.

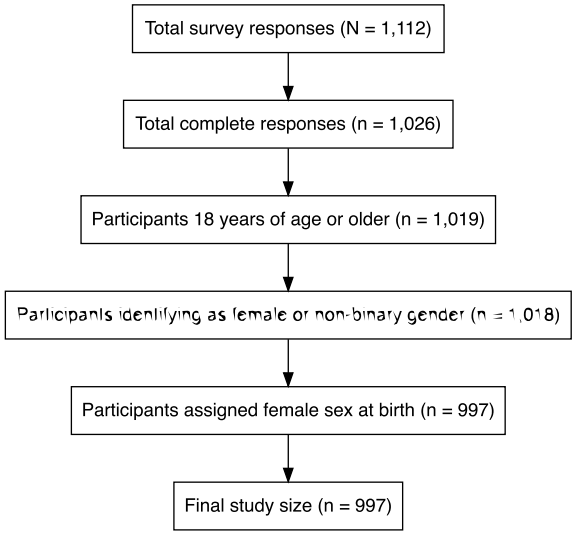

Figure 2. Survey completion and exclusion criteria

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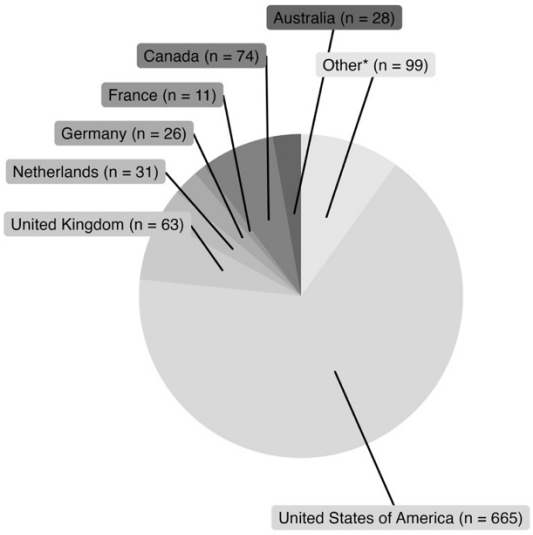

Figure 3. Athletes' countries of residence

**Other* countries, which had fewer than 10 survey respondents, were the following: Australia, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, Indonesia, Ireland, Israel, Italy, Japan, Luxembourg, Malaysia, New Zealand, Norway, Philippines, Poland, Portugal, Romania, Singapore, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, and Thailand

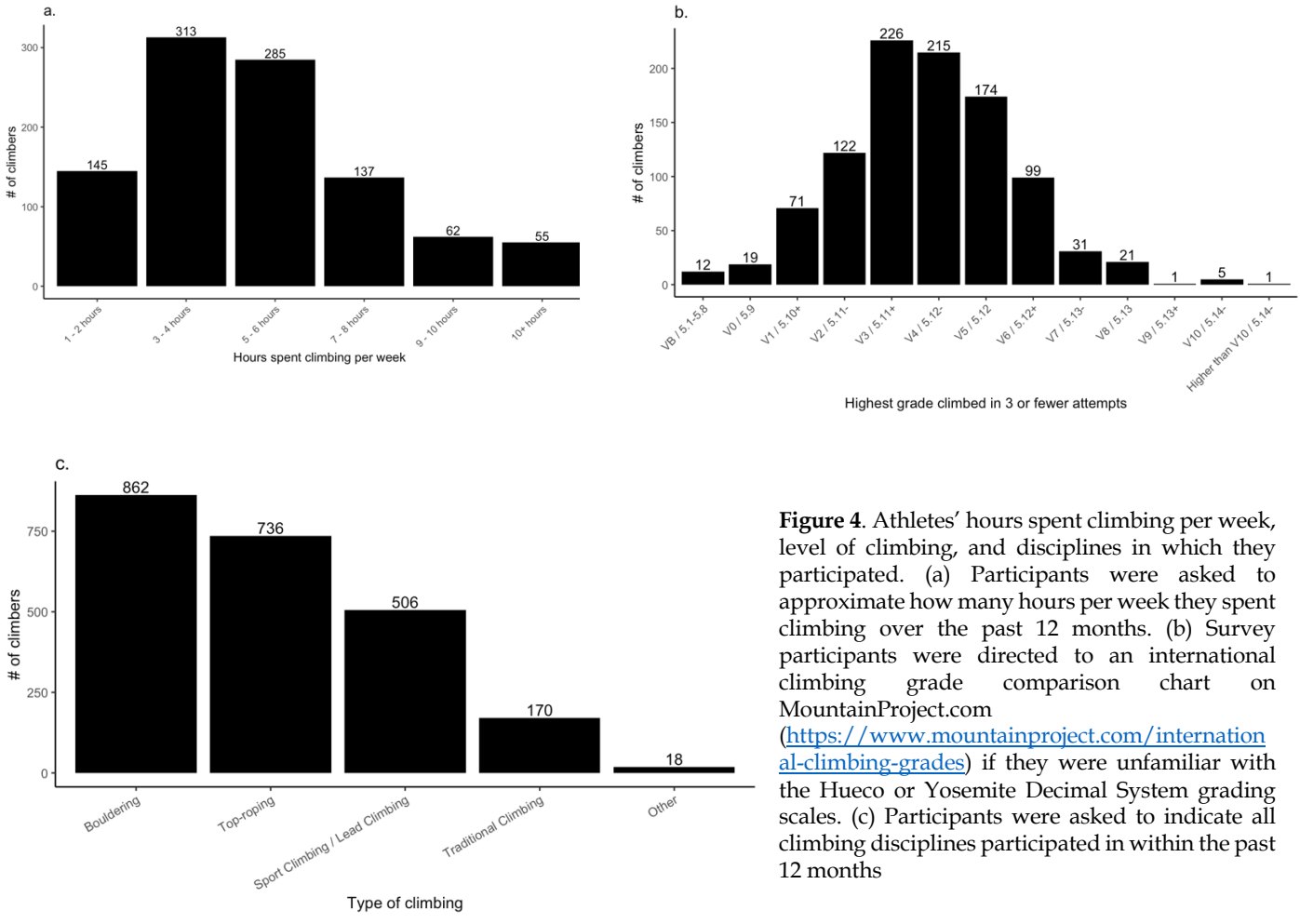

Figure 4. Athletes' hours spent climbing per week, level of climbing, and disciplines in which they participated. (a) Participants were asked to approximate how many hours per week they spent climbing over the past 12 months. (b) Survey participants were directed to an international climbing grade comparison chart on MountainProject.com (https://www.mountainproject.com/international-climbing-grades) if they were unfamiliar with the Hueco or Yosemite Decimal System grading scales. (c) Participants were asked to indicate all climbing disciplines participated in within the past 12 months

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Table 1. Demographic characteristics of 997 athletes

	No injury in the past 12 months (n = 511)	*Injury in the past 12 months (n = 486)*	*P-value*
Gender			
Female	486 (95.1%)	469 (96.5%)	0.348[a]
Non-binary	25 (4.9%)	17 (3.5%)	
Current age (years)			
Mean (SD)	31.0 (7.57)	30.7 (7.04)	0.506[b]
Median [Min, Max]	30.0 [18.0, 71.0]	30.0 [18.0, 69.0]	
Years of climbing experience			
Mean (SD)	6.15 (6.72)	6.22 (6.62)	0.873[b]
Median [Min, Max]	4.00 [0, 47.0]	4.00 [0, 68.0]	
Height (inches)			
Mean (SD)	65.0 (2.81)	65.0 (2.99)	0.792[b]
Median [Min, Max]	65.0 [52.0, 73.0]	65.0 [58.0, 83.0]	
Weight (pounds)			
Mean (SD)	137 (24.2)	136 (26.5)	0.666[b]
Median [Min, Max]	134 [59.0, 265]	133 [60.0, 420]	

[a] Chi-square test; [b] t-test; SD, standard deviation

The primary outcome studied was the incidence of one or more climbing-related injuries in the past 12 months. For the purposes of this study, a climbing-related injury was defined as an injury that required the athlete to end the current climbing session or led them to pause regular climbing for a period of time. Four hundred eighty-six participants (48.7%) reported at least one injury in the past year. Athletes who experienced no injury in the past year were similar in gender, age, years of climbing experience, height, and weight to those who did experience injury (Table 1).

Of the 486 athletes who reported at least one injury in the past year, more than half (n = 275, 56.6%) experienced only one (Table 2).

Table 2. Number of injuries experienced in the past 12 months

Number of injuries	*Number of athletes (N = 997)*
0	511 (51.3%)
1	275 (27.6%)
2	150 (15.0%)
3	47 (4.7%)
4	6 (0.6%)
5	1 (0.1%)
More than 5	7 (0.7%)

BMI, history of one or more physical health conditions, diagnosis of a non-eating disorder mental health condition, history of a lost period for 90 days or longer, amenorrhea, low BMD, and warming up with only climbing were not significantly associated with incidence of injury in the past year. However, we found a high prevalence of menstrual dysfunction in this group, with 54 participants (5.4%) reporting a formal diagnosis of amenorrhea and 254 (25.5%) reporting a history of losing their period for 90 or more days for reasons not due to pregnancy, hormonal contraception, hysterectomy, or menopause. Diagnosis of an eating disorder, participation in bouldering, lack of regular participation in sports other than climbing, regular participation in mobility- or flexibility-focused activities, regular hang board training, and warming up with activities other than climbing itself were all positively associated with incidence of injury in the past year (Table 3).

Overall, 111 participants (11.1%) reported an eating disorder and 54 (5.4%) had a formal diagnosis of amenorrhea. We also found that, among those with a formal diagnosis of amenorrhea, 23 (42.6%) had an eating disorder, compared to only 88 climbers (9.3%) among those without a formal diagnosis of amenorrhea.

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Climbers who spent more time per week climbing, participated in bouldering, and regularly participated in mobility-focused exercises were more likely to have experienced an injury in the past year even while adjusting for age, percentage of time spent climbing indoors, diagnosis of an eating disorder, highest climbing grade above V3, regular hang board training, regular warming up, diagnosis of a physical health condition, and diagnosis of amenorrhea (Table 4). Climbers who regularly participated in other sports were less likely to have experienced injury in the same model. History of an eating disorder was significantly associated with injury in the past year while adjusting only for age, diagnosis of amenorrhea, and diagnosis of a physical health condition.

Table 5 presents 766 discrete climbing injuries in further detail; 672 (87.7%) reported injuries occurred while climbing indoors, 564 (73.6%) occurred while bouldering, and 526 (68.7%) had an acute onset.

However, it is important to note that, on average, athletes reported climbing indoors 83.2% of the time, so the high proportion of injuries that occurred while climbing indoors is more likely reflective of the time spent climbing in that setting rather than an inherent higher risk of injury while climbing indoors. Similarly, the distribution of injuries that occurred while bouldering, top-roping, sport climbing, and traditional climbing also reflects survey respondents' participation in those disciplines. Only 27 (3.5%) reported injuries required surgery, but 549 (71.7%) led the climber to pause regular climbing for more than a week. Athletes were able to return to climbing after 752 (98.2%) reported injuries and were able to return to their pre-injury level of climbing after 617 (80.5%) of them. Most (n = 474; 61.9%) of the reported injuries were to the upper extremities (shoulder, arm, elbow, wrist, or hand), followed by 222 (29.0%) to the lower extremities (hip, leg, knee, ankle, or foot).

While we were unable to calculate an exact injury rate per 1,000 climbing hours to compare with rates found in prior studies, it was possible to estimate. Study participants reported 0, 1, 2, 3, 4, 5, or more than 5 climbing injuries over the past 12 months. They also reported the number of hours they typically spent climbing per week as 1 to 2 hours, 3 to 4 hours, 5 to 6 hours, 7 to 8 hours, 9 to 10 hours, or 10+ hours. Counting more than 5 climbing injuries in the past year as 5 (only 7 participants responded this way) and the hours spent climbing as the mean of the two bounds or 10 hours for a response of 10+ (only 55 participants responded this way), we calculated an estimated injury rate of 2.97 per 1,000 hours spent climbing.

Table 3. Results of bivariate analysis to investigate potential risk factors for climbing-related injury

	No injury in the past 12 months (n = 511)	***Injury in the past 12 months (n = 486)***	***P-value***
BMI			
< 18.5	29 (5.7%)	27 (5.6%)	0.542
Between 18.5 and 24.9	369 (72.2%)	367 (75.5%)	
Between 25.0 and 29.9	90 (17.6%)	77 (15.8%)	
30.0 or higher	23 (4.5%)	15 (3.1%)	
History of one or more physical health conditions			
No	355 (69.5%)	310 (63.8%)	0.066
Yes	156 (30.5%)	176 (36.2%)	
History of one or more mental health conditions			
No	236 (46.2%)	194 (39.9%)	0.053
Yes	275 (53.8%)	292 (60.1%)	
History of non-eating disorder mental health condition(s)			
No mental health conditions	236 (50.8%)	194 (46.1%)	0.186

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History of non-eating disorder mental health condition(s)	229 (49.2%)	227 (53.9%)	
History of eating disorder(s)			
No mental health conditions	236 (83.7%)	194 (74.9%)	*0.015*
History of eating disorder(s)	46 (16.3%)	65 (25.1%)	
History of lost period for 90 days or longer			
No	360 (70.5%)	318 (65.4%)	0.325
Yes	125 (24.5%)	129 (26.5%)	
Not applicable / Don't remember	26 (5.1%)	39 (8.0%)	
History of amenorrhea diagnosis			
No	484 (94.7%)	459 (94.4%)	0.960
Yes	27 (5.3%)	27 (5.6%)	
History of low BMD diagnosis			
No	503 (98.4%)	474 (97.5%)	0.429
Yes	8 (1.6%)	12 (2.5%)	
Participation in bouldering			
No	84 (16.4%)	51 (10.5%)	*0.008*
Yes	427 (83.6%)	435 (89.5%)	
Regular participation in sports other than climbing			
No	120 (23.5%)	156 (32.1%)	*0.003*
Yes	391 (76.5%)	330 (67.9%)	
Regular participation in mobility- or flexibility-focused activities			
No	178 (34.8%)	136 (28.0%)	*0.023*
Yes	333 (65.2%)	350 (72.0%)	
Regular hang board training			
No	458 (89.6%)	394 (81.1%)	*<0.001*
Yes	53 (10.4%)	92 (18.9%)	
Typically warms up for a climbing session			
No	73 (14.3%)	41 (8.4%)	*0.005*
Yes	438 (85.7%)	445 (91.6%)	
Warm-up includes activities other than climbing			
Does not warm up	73 (21.5%)	41 (11.1%)	*<0.001*
Warm-up includes activities other than climbing	267 (78.5%)	328 (88.9%)	
Warm-up only includes climbing			
Does not warm up	73 (29.9%)	41 (25.9%)	0.454
Warm-up only includes climbing	171 (70.1%)	117 (74.1%)	
Warms up with other activities versus climbing only			
Warm-up includes activities other than climbing	267 (61.0%)	328 (73.7%)	*<0.001*
Warm-up only includes climbing	171 (39.0%)	117 (26.3%)	

[a] Chi-square test. $P < 0.05$ are italicized.
[b] For reasons not due to pregnancy, hormonal contraception, hysterectomy, or menopause.

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Table 4. Results of multivariate analysis to determine risk factors significantly associated with injury

Risk factor	*Baseline category*	*Odds Ratio*	*95% Confidence Interval*	*P-value*
*Climbing 3–4 hours per week**	Climbing 1–2 hours per week	1.55	1.01–2.40	*0.046*
*Climbing 5–6 hours per week**	Climbing 1–2 hours per week	2.12	1.37–3.31	*<0.001*
*Climbing 7–8 hours per week**	Climbing 1–2 hours per week	2.40	1.43–4.06	*<0.001*
*Climbing 9–10 hours per week**	Climbing 1–2 hours per week	2.35	1.24–4.53	*0.009*
*Climbing 10+ hours per week**	Climbing 1–2 hours per week	4.73	2.25–10.37	*<0.001*
Regular participation in other sports†*	No regular participation in other sports	0.65	0.48–0.87	*0.005*
*Participation in bouldering**	No participation in bouldering	1.69	1.10–2.64	*0.018*
*Regular participation in mobility activities**	No regular participation in mobility activities	1.34	1.00–1.78	*0.049*
History of an eating disorder‡	No history of an eating disorder	1.53	1.02–2.33	*0.043*

*Adjusting for age, percent of time climbing indoors, diagnosis of an eating disorder, highest climbing grade above a V3, regular hang board training, regular warming up, diagnosis of a physical health condition, and diagnosis of amenorrhea.
†Running (361 participants), yoga (335), weightlifting (310), cycling (238), skiing (100), swimming (68), Pilates (65), dance (47), snowboarding (29), tennis (22), soccer (19), and volleyball (15) were the most commonly reported other sports. Except for skiing (P = 0.007), no significant association between injury and any individual sport with more than 10 reported participants was identified.
‡Adjusting for age, diagnosis of amenorrhea, and diagnosis of a physical health condition.

Table 5. Characterization of 766 discrete climbing injuries reported in 997 participants

	Area of body injured				
	Lower extremity [a] ***(n = 222)***	***Torso (n = 27)***	***Upper extremity*** [b] ***(n = 474)***	***Head or neck (n = 43)***	***Overall (n = 766)***
Location of climbing when injury occurred					
Indoors	188 (84.7%)	25 (92.6%)	422 (89.0%)	37 (86.0%)	672 (87.7%)
Outdoors	34 (15.3%)	2 (7.4%)	52 (11.0%)	6 (14.0%)	94 (12.3%)
Type of climbing being practiced when injury occurred					
Bouldering	166 (74.8%)	20 (74.1%)	349 (73.6%)	29 (67.4%)	564 (73.6%)
Top-rope	21 (9.5%)	4 (14.8%)	74 (15.6%)	6 (14.0%)	105 (13.7%)
Sport / Lead	31 (14.0%)	2 (7.4%)	47 (9.9%)	6 (14.0%)	86 (11.2%)
Trad	4 (1.8%)	1 (3.7%)	4 (0.8%)	2 (4.7%)	11 (1.4%)
Acute or chronic onset					
Acute	181 (81.5%)	20 (74.1%)	288 (60.8%)	37 (86.0%)	526 (68.7%)
Chronic	41 (18.5%)	7 (25.9%)	186 (39.2%)	6 (14.0%)	240 (31.3%)

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Required surgery					
No	208 (93.7%)	25 (92.6%)	465 (98.1%)	41 (95.3%)	739 (96.5%)
Yes	14 (6.3%)	2 (7.4%)	9 (1.9%)	2 (4.7%)	27 (3.5%)
Paused climbing for more than 1 week due to injury					
No	50 (22.5%)	4 (14.8%)	145 (30.6%)	18 (41.9%)	217 (28.3%)
Yes	172 (77.5%)	23 (85.2%)	329 (69.4%)	25 (58.1%)	549 (71.7%)
Able to return to climbing following injury					
No	6 (2.7%)	0 (0%)	7 (1.5%)	1 (2.3%)	14 (1.8%)
Yes	216 (97.3%)	27 (100%)	467 (98.5%)	42 (97.7%)	752 (98.2%)
Able to return to prior level of climbing following injury					
No	45 (20.3%)	5 (18.5%)	90 (19.0%)	9 (20.9%)	149 (19.5%)
Yes	177 (79.7%)	22 (81.5%)	384 (81.0%)	34 (79.1%)	617 (80.5%)

[a] Hip, leg, knee, ankle, or foot.
[b] Shoulder, arm, elbow, wrist, or hand.

DISCUSSION

To our knowledge, this study is the first to investigate sex-specific risk factors for injury among a general population of female climbers. Previous studies did not specifically inquire about risk factors unique to women or to which women are more susceptible, except for one which was limited to elite female climbers.[27] The demographic characteristics collected in this study show that our population of respondents encompasses a diverse set of ages, heights, weights, climbing experiences, climbing levels, and training habits and is more representative of recreational adult female climbers today.

A key finding of our study was that history of an eating disorder was significantly associated with injury in the past year, even after adjusting for age, diagnosis of amenorrhea, and diagnosis of a physical health condition. This is consistent with the significant body of research showing the harmful health effects of consistent under-fueling leading to low energy availability in athletes.[35,36] In climbing, an antigravitational sport, the perception is common that a high strength-to-weight ratio is beneficial for better climbing performance, and this belief has been linked to disordered eating and negative body image among climbers who strive toward a lower body weight.[37,38] Joubert et al.[39] found the prevalence of disordered eating to be more than double in female sport climbers (16.5%) compared to male climbers (6.3%) and Monedero et al.[40] found that in a population of advanced and elite climbers, only the female climbers had energy intakes significantly lower than their calculated energy requirements. Clinicians and trainers should be aware that climbers with eating disorders could be at increased risk for injury, and referrals for nutrition counseling or psychological support may be warranted when disordered eating is identified.

Menstrual dysfunction, a sign of chronic low energy availability in female athletes, was not found to be significantly associated with injury in our study. However, some conditions, such as amenorrhea and low BMD, may have been underestimated in this study because of underdiagnosis and the relatively young age of our study population. Still, the prevalence of a formal amenorrhea diagnosis and a history of a lost period for 90 days or longer for reasons not due to pregnancy, hormonal contraception, hysterectomy, or menopause, which is near sufficient for a diagnosis of amenorrhea, were both higher in our study population than current estimates of amenorrhea among the general population of women of reproductive age (approximately 3–4%).[41] Further, the proportion of women in this

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study who reported a lost period for 90 days or longer (25.0%) is similar to the proportion of female sport climbers who presented with current amenorrhea (15.8%) or irregular menstrual cycles (12.3%) in a 2022 study.[42] These findings merit closer investigation into why the prevalence of amenorrhea is so high among female climbers and whether it may have detrimental effects over time as they continue climbing into older ages.

Another important finding was that regular participation in sports other than climbing was linked to a lower risk of injury. This is consistent with the growing body of literature linking sport specialization to higher injury risk among young athletes.[43,44] In a study investigating female high school athletes, higher levels of specialization were associated with greater overall injury risk as well as greater risk of concussions and stress fractures.[45] Prior research has investigated sport specialization among youth climbers with conflicting results. Barrile et al.[25] found no significant association between participation in other sports and climbing-related pain or injury in a population of competitive youth climbers. Another study found that late specialization in climbing was linked to a higher likelihood of lifetime injury, but found no difference in the incidence of overuse injuries between early and late specializers.[46] However, these findings have limited generalizability to climbers who are skeletally mature; prior research has identified physiological responses to rock climbing in youth climbers and corresponding unique injury patterns.[47] Our study contributes a novel new insight into sport specialization and the potential benefits of cross-training among adult female climbers.

Our finding that participation in the bouldering discipline was associated with an increased risk of injury in the past 12 months aligns with some prior studies.[4] However, the existing literature presents conflicting evidence, with several other studies suggesting the lead discipline to be a risk factor for injury.[8] Such discrepancies may stem from variations in study design; definitions of injury; type of injury being investigated, such as acute or chronic; and climbing environment, such as indoor versus outdoor climbing. Further, female climbers may approach roped and non-roped climbing disciplines differently from their male counterparts, as variations in risk tolerance have been observed in athletes of different sexes.[48–50] In any case, our study reinforces that female climbers should be aware of the potentially higher injury risk associated with bouldering and use proper climbing and falling technique and protective equipment.

We also found a weak but significant association between regular participation in mobility- or flexibility-focused activities and injury in our multivariate analysis. We are not aware of other studies looking specifically at this risk factor, but one prior study investigated anthropometric characteristics of advanced and elite female climbers and found no significant differences in upper or lower body mobility among skill levels.[51] This suggests that injury could be attributed to participation in these activities rather than to flexibility per se. However, those who experienced injury in the past year may have been more likely to start engaging in flexibility- or mobility-focused activities; thus, previous injury itself may have been a confounder. Female climbers who are seeking to improve to high skill levels can consider referring to prior research to guide their flexibility or mobility goals but should be aware that there is currently no consensus surrounding whether flexibility or mobility training changes their risk of climbing injury.

Generally, the profile of reported climbing injuries found in our study is consistent with the literature. As in prior studies, most reported injuries were in the upper extremities, but a greater proportion of acute injuries occurred in the lower extremities.[4,19] A recent study by Grønhaug et al. demonstrated significant differences in incidence of injury to the feet/ankles, neck, head, shoulder, elbow, and fingers between men and women and that the most common site of injury for women was the shoulders, compared to the fingers in men.[29] Although we did not inquire about specific area of the upper extremity injured, we similarly found that upper extremities were the most commonly injured area in our study population of female climbers and that approximately half of all study participants had experienced at least one injury in the past 12 months. Overall, most injuries did not require surgical intervention and were associated with a high rate of return to sport, again consistent with previous findings in the literature.[4,16,19]

Limitations

This study was a cross-sectional survey study and thus was not able to assess temporal relationships or causation. As with any survey, there is also the question of generalizability to the true population of female climbers. Study participants were recruited primarily via social

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media, which could have skewed our sample towards younger climbers who are more active on online climbing forums. The sample population might also have been slightly skewed geographically because of our recruitment methods. However, there was by far the most engagement with the recruitment posts on Reddit.com and MountainProject.com, which have widespread use and thus presumably diverse geographic representation nationally and internationally. Further, the years of climbing experience, level of climbing, and hours per week spent climbing reported in this study are very similar to those found in another recent study with data collected from 2021[29] via social media solicitation and international representation. We also could not compare risk factors, training behaviors, and injuries between male and female climbers since we exclusively surveyed female climbers. Lastly, this study is limited by the potential for self-selection bias and recall bias. Climbers who have experienced injuries might have been more likely to participate and complete the survey. Further, survey participants were asked to recall their injuries in the past 12 months and are more likely to report the more severe and thus more memorable injuries. However, our outcome measures for injury severity and incidence are similar to those found in previous studies.

CONCLUSION

Our findings underscore the potential negative health implications of chronic low energy availability in the demanding sport of rock climbing, particularly among female climbers who are more susceptible to developing eating disorders, amenorrhea, and low BMD. Additionally, incorporating cross-training by participating in sports outside of climbing may be protective against climbing injuries. Our data also suggest a potentially higher risk of injury associated with bouldering compared to other popular climbing disciplines. Other behaviors such as regular hang board training and warming up with activities other than climbing were also linked to injury in the past year; however, further research is required to determine whether these risk factors persist when adjusting for other relevant demographic and climbing characteristics. Continued investigation into safe training practices and preventative measures is essential to ensure the long-term health and performance of recreational female climbers.

Conflict of Interest Statement
The authors declare no conflicts of interest with the contents of this study.

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