Injury 56 (2025) 112672

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Severity of mountain accidents in Catalonia over the period 2011 to 2021: An ordinal regression analysis

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ARTICLE INFO

Keywords:
Mountain accident
Severity of accident
Traumatic injury
Ordinal regression
Epidemiology

ABSTRACT

Mountain accidents have increased over the last decade all around the globe mostly due to a raise of mountain activity practitioners. Outcomes of accidents usually imply evacuation, traumatic injuries or even cardiovascular events. Sex, age, activity, altitude, experience, and equipment adequacy relate to accidents as direct causes or moderators of accident severity. This study focuses on the mountain accidents in Catalonia with descriptive and ordinal regression analysis aiming to characterize a victim vulnerability profile, which remains largely unexplored. The current sample includes 3257 mountain rescue operations from the Catalan Fire Department records between 2011 and 2021. Descriptive analysis showed that the most common profile was being hiker (63 %), climber (11.6 %), mountain biker (10.2 %), man (60.3 %), going in group (84.3 %), occurring in weekends (53.7 %), and suffering traumatic events (61.4 %) or needing technical support (20.4 %). Moreover, the main causes of fatality were falls and cardiovascular issues with the latter showing the higher fatality rate (55.5 %). Ordinal regression analysis explained a modest amount of variance (Nagelkerke $R^2 = 0.12$), suggesting that predictors of higher severity were Group, Altitude, Male, Gathering, Mountain Biking and other practices such as Hunting. Recommendation to rescue teams comprise standardizing and potentiate data collection, conducting awareness campaigns targeted mainly to hikers, mountain bikers and elderly men, and to reinforce awareness campaigns and rescue teams during weekends.

Introduction

Trends on practicing mountain activities

During the last decades, the popularity of mountain activities has substantially raised. In USA, the 2023 Outdoor Participation Trends Report [1] showed that participation in outdoor recreation increased from almost 140 million people in 2007 to more than 160 million in 2022 with the largest increase between 2019 and 2022, with more participants hiking, trail running, snowshoeing and mountain biking. Also climbing is present among the youngest participants. In Spain the trend of licenses expedited by the Spanish Mountain Federation raised from 233.161 sport federation licenses in 2018 to 289.605 in 2022 [2]. Finally, the number of issued Catalan Mountain Federation licenses also increased from 15.449 to 44.654 during the past 20 years [3,4].

Mountain activities and rescue epidemiology

In mountain injury epidemiologic most of studies are descriptive [5–7] and most of the data has been collected and provided by rescue workers, who engage professionally or voluntarily in helping and saving people from a dangerous or difficult situation, with severe injuries, or at a high risk of death [8]. Table in Supplementary offers an overview of data collected in different countries. Overall, mountain accidents, through the large number of activities, injuries and deaths, have been linked to an increased health and financial burden [5]. Furthermore, it includes the rescue workers as they are at high-risk of developing post-traumatic stress disorder (PTSD) [9,10] and suffering occupational accidents [10]. Finally, in Catalonia, Saladié et al. [11], described the spatial and frequency changes on rescue operations due to the end of COVID-19 lockdown.

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https://doi.org/10.1016/j.injury.2025.112672
Accepted 2 August 2025
Available online 8 August 2025

Victim profile and risk factors

The major victim profile reported is being hiker followed by being canyoner, climber or skier, and being young or old adult male [5–7,12–14]. However, accident severity levels vary with age and sex. First, older people show a higher probability of becoming injured or deceased [12,13,15]. Second, some studies report that, excluding death, male victims are at a lower risk of being impacted when rescued than female victims are [16]. Other studies inform that males are more commonly injured and victims of accidents even considering absolute and relative frequency across activities [6], or even in specific activities such as mountain biking and climbing [17–20]. Finally, accounting for sociologic factors, more rescues happen during weekend and summer vacation while some natural protected areas are more prone to bear accidents than others [5–7,11,13].

Typical causes and outcomes

Common causes of accidents include losing one's way, technical inability, physical exhaustion, and falling, with the last being notably more frequent [6,7,13,14]. Also, fortuite objective hazards such as rock falling or avalanches are typical causes [6,13].

Fractures, sprains and traumas stand out as the more typical injuries at low to moderate severity levels with the last being also present in more severe and fatal accidents [7]. For severe and fatal accidents, other affectations such as cardiopulmonary issues have been detected, mostly in older male as illness and decease causes [7,21–23]. Finally, hypothermia has also been registered [21]. Within specific activities, Bigdon et al. [24] found that mountain biking typically leads to fractures affecting the upper extremities such as clavicle, hand and wrist. They also found that in climbing, injuries often impact the lower extremities (particularly the foot and ankle), usually resulting from falls. Finally, sex-specific injury patterns reveal that men experience multiple injuries more frequently and significant blood loss than females while females are more prone to fractures, especially in the ankle or foot [16].

The present study

Using an epidemiologic retrospective approach over a 11-year period in Catalonia, the main objective of the present work is to characterize the vulnerability profile of a mountain accident victim. We aim to model the relationship between individual/group characteristics, activity and temporal variables with the severity of mountain accidents. Catalonia is internationally famous among mountain practitioners, however there is scarce data available regarding severity of accidents nor the victim profile.

Present study methodology goes one step farther than Vanpoulle et al. [13], who dichotomized severity in a logistic regression analysis, by dividing the severity into four levels and capturing a broader spectrum of severity, which represents a continuous variable [25]. Hence, for the categorical approach to severity, the methodology of choice is ordinal regression analysis, explained in 2.3.2 section.

Based on the available evidence, we hypothesize that the number of rescues and injuries has increased according to popularity of mountain sports in recent years [1,3,4]. Moreover, we expect that most vulnerable profile will be hikers and men during weekend and summer holidays [13,26].

Materials and methods

Sample description

The present study is a subset of the operation reports database of the Catalan Fire Department, within the Directorate General of Fire Prevention, Extinction and Rescue Services (DGPEIS). The present data contain the mountain rescue operation reports and have been depurated and structured. All rescue operations used in the present study occurred between the 1st of January 2011 and the 31th of December 2021 within Catalonia. The final sample consisted of 3257 rescue operations. All of them comprised at least the health outcome of the incident and the activity related to the incident. Data source, collection and curation procedure is available in Supplementary S2.

[11]

Measures and coding of variables

Table 1 describes the variables included in the study. They were divided into 4 groups depending on whether (a) registered by de DGPEIS software, (b) included by the operation leader during the final report of the rescue, (c) gathered from text reports of the phone operators, or (d) recoded from previous variables. The response variable of the present study is severity. Compared with Illness Severity Classification (IIC) – UIAA MedCom Score [27], in our study uninjured is equivalent to a score of 1, injured/ill is equivalent to 2–4 score, life risk is equivalent to score of 5 and death is equivalent to 6–7 score. Similar strategies have been adopted in previous studies [7]. Type of injury or cause of rescue in uninjured cases variables were directly based on the terminology reported by the rescuers and phone operators which is based on their first aid skills [7,13]. However, due to the available data and the study purpose, the classification into broader variables changed slightly. The final broad categories were:

a) Traumatic: physical injuries caused by external forces.
b) Conscious/heat: altered consciousness without loss including fainting, dizziness, heatstroke, hypoglycemia and convulsions.
c) Cardiovascular: tachycardia, strokes, heart attacks and cardiac arrests.
d) Breath: pneumothorax and asthma.
e) Anxiety: feeling of fear, dread and uneasiness reactive to stress situation.
f) Others: other causes non included in previous categories.

Among traumatic we considered fatal falls, traumatic brain injuries (TBI), fractures, hemorrhages, dislocations, sprains, wounds or scratches, contusions or muscular issues.

For the rescue duration, duration above 48 h was considered an outlier. Longer intervention times imply that the operation remains unarchived due to administrative or judicial procedures. Regarding time and date variables, and based on results in Supplementary material S4, they were recodified as dichotomous (weekend and summer).

Statistical analysis

Two statistical analyses were conducted to address the objectives and hypothesis of the present study: a descriptive data analysis and an ordinal regression analysis. All analyses were conducted with R software [28]. Data from this study is available upon request, subject to approval from DGPEIS.

Exploratory, descriptive and basic inferential data analysis

Absolute and relative frequency of the accidents, measures of central tendency and dispersion statistics were provided for each variable in Table 1 according to its quantitative or qualitative nature. The proportions of qualitative variables were compared using χ^2 or Fisher's exact test when assumptions of the χ^2 test were not met [29,30]. Quantitative variables were compared with severity levels using the non-parametric Kruskal Wallis test [31]. Significance levels were set at $p \leq 0.05$.

Ordinal regression analysis

Ordinal regression was used to predict the severity of mountain accidents. This method preserves the natural ordered responses and avoids

Table 1
Name, description, type, and unit of variables included in the present study.

Name	Description	Type of variable	Label
Automatically recorded by the emergency management software			
Time and Date	Date and time the incident is first reported and finished	Discrete	HH:MM:SS/DD-MM-YYYY UTC/GMT +1
Altitude	Altitude above sea.	Continuous	Meters
Reported by the operation leader			
Activity	Mountain activity practiced by the victim/s.	Nominal	Hiking, Snow activities, Gathering, Climbing, Canyoning, Biking, Other cultural[a]
Equipment Adequacy	Subjective evaluation of the rescue leader about the equipment adequacy	Binary	Yes, No
Dangerous Context	Subjective evaluation of the rescue leader about the exposure of the victims to a dangerous unjustified context	Binary	Yes, No
Manually categorized by the researcher			
Sex	Of the victim or of the overall group composition if multi-victim incident.	Nominal	Men, Women, Mixed
Group Size	[#]	Nominal	Individuals, Group or Competition
Severity	[#]	Ordinal	Uninjured, Injured/Ill, Life Risk, Death
Broad Type of injury/ill or cause of rescue	[#]	Nominal	Traumatic, Conscious/heat, Cardiovascular, Breath, Anxiety, Others
Type of injury/ill or cause of rescue	[#]	Nominal	*Traumatic type of injury:* Fatal Fall[c], TBI[d], Fracture, Hemorrhage, Dislocation, Sprain, Wound or scratch, Contusion and Muscular. *Other type of injuries or ill:* Anxiety, Breath, Cardiovascular, Conscious/heat, Others.
Recoded by the researcher			
Rescue duration	Time expended between the 112 alarm and the end of the operation	Continuous	Minutes
Weekend[e]	Time coded as belonging to Saturday and Sunday or not	Binary	Yes, No
Summer[e]	Time coded as belonging to July and August or not	Binary	Yes, No

[a] It includes free time sport practices including hunting or social and sportive events.
[b]When the outcome was uninjured.
[c] Category created as most part of the reports did not specify the traumatic cause.
[d] Traumatic Brain injury.
[e] Decision made after descriptive analysis.
[#] Explained in text.

the pitfalls of using ANOVA-type models on ordered categorical data [32,33]. For the present study, the cumulative model approach was chosen as severity represents a continuous variable [25,32]. We first estimated two basic models dividing predictor variables into two groups: time related and accident related. Accidents with missing data on the predictors were excluded allowing a direct comparison between models. Secondly, to select the predictor variables for each model, multicollinearity and proportional odds assumption were tested with the Variance Inflation Factor (VIF) [34] and the Brant test [35], respectively. If increased multicollinearity was detected, variables were rejected according to the model fit improvement when deleted. If proportional odds assumption were rejected a non-proportional approximation was run with the *VGAM* R package [36]. Third, by only keeping the significant variables and interactions of each model, two final models were estimated: one only joining the significant variables of the initial models and the other also adding cross fold interactions between accidents and time variables.

Finally, all models fit was evaluated and compared using the Deviance, the Nagelkerke pseudo-R^2, the Akaike Information Criterion (AIC) [37] and the Likelihood Ratio (LR) Test [38]. Lower values of Deviance and AIC would suggest a better fit. Higher values of the Nagelkerke pseudo-R^2, indicate a higher proportion of variability in the response variable explained by the model [39]. Significant values ($p \leq 0.05$) in the comparison between models with the LR test would imply statistically significant differences. According to the best fit criteria, the best model was selected, and the Pearson residuals and influential points (hat values) were checked [40]. Finally, the final model was conducted and described by the coefficients estimates and the odds ratio.

Results

Descriptive analyses

Table 2 shows the absolute and relative frequency over the severity levels of the different categorical variables. Among the victims, 21.4 % were unharmed, 70.1 % were injured or ill, 5.04 % faced life risk, and 3.53 % resulted in death. Hiking was the most frequent activity (63 %), but mountain biking, climbing and other cultural activities were more frequent in more severe accidents. Inadequate equipment was involved in 8.29 % of incidents. Accidents happened mostly in groups (84.3 %). Sex analysis indicated males (60.3 %) were more frequently involved in incidents and weekend accidents accounted for 53.7 % of the total, with higher severity during weekends. Pairwise analysis showed a generalized statistically significant differences across severity levels ($p < 0.05$) on all variables except on summer.

As shown in Supplementary material S1, life risk accidents tended to happen at lower altitudes, while unharmed incidents occurred at higher. The duration of rescues was found to be longer in fatal accidents and shorter in incidents resulting in mild injuries.

Fig. 1 displays the yearly number of rescues trend which raised only in mild to moderate injured/ill severity accidents. Fig. 1 and Table 3 also show that traumatic injuries were the main outcome with 65.09 % of the accidents, followed by the technical support with 21.59 %. However, regarding fatal accidents, the main outcome was cardiovascular accounting for half of the fatal accidents (57.5 %) even being one of the less common causes (3.94 %). Table 4 also shows that most of the traumatic accidents were fractures followed by sprains and contusions. However, all of them led mainly to mild/moderate injuries. When considering severe and fatal accidents, fatal falls causing polytraumatic and/or traumatic brain injuries were the main causes of accidents.

Ordinal regression analysis

The data subset used in the ordinal regression analyses consisted of 2285 accidents. Due to sparse data on some categories of variables sex and group, they were dichotomized removing mixed sex and adding competition to group response, respectively.

The proportional odds assumption of the predictors was rejected for the two broad models with highly significant χ^2 values ($p < 0.001$). However, we kept the proportional assumption on non-significant variables. We also deleted inflated predictors (VIF > 10) (see Supplementary S7).

Table 2
Prevalence and difference statistical testing of the categorical variables involved in mountain rescues across different levels of severity. Percentages between brackets indicate the relative frequency at each severity level. P overall shows the signification of the categorical tests (χ^2 or Fisher). The most relevant outcomes are in boldface.

	N (%)	Unharmed 696 (21.4 %)	Injured/Ill 2282(70.1 %)	Life Risk 164(5.04 %)	Death 115(3.53 %)	P overall
Activity	3257					<0.001
Hiking	2052 (63 %)	446 (64.1 %)	1472 (64.5 %)	70 (42.7 %)	64 (55.7 %)	
Snow	142 (4.36 %)	24 (3.45 %)	108 (4.73 %)	6 (3.66 %)	4 (3.48 %)	
Gathering	86 (2.64 %)	26 (3.74 %)	52 (2.28 %)	3 (1.83 %)	5 (4.35 %)	
Climbing	377 (11.6 %)	135 (19.4 %)	205 (8.98 %)	29 (17.7 %)	8 (6.96 %)	
Canyoning	67 (2.06 %)	19 (2.73 %)	45 (1.97 %)	2 (1.22 %)	1 (0.87 %)	
Mountain Biking	332 (10.2 %)	12 (1.72 %)	272 (11.9 %)	34 (20.7 %)	14 (12.2 %)	
Others	201 (6.17 %)	34 (4.89 %)	128 (5.61 %)	20 (12.2 %)	19 (16.5 %)	
Dangerous	3257					<0.001
No	1745 (53.6 %)	316 (45.4 %)	1266 (55.5 %)	91 (55.5 %)	72 (62.6 %)	
Yes	1512 (46.4 %)	380 (54.6 %)	1016 (44.5 %)	73 (44.5 %)	43 (37.4 %)	
Equipment Adequacy	3257					<0.001
No	270 (8.29 %)	126 (18.1 %)	119 (5.21 %)	17 (10.4 %)	8 (6.96 %)	
Yes	2987 (91.7 %)	570 (81.9 %)	2163 (94.8 %)	147 (89.6 %)	107 (93.0 %)	
Group Composition	2845					.
Alone	391 (13.7 %)	132 (19.3 %)	233 (12.1 %)	8 (5.76 %)	18 (17.8 %)	
Group	2399 (84.3 %)	550 (80.3 %)	1640 (85.4 %)	128 (92.1 %)	81 (80.2 %)	
Competition	55 (1.93 %)	3 (0.44 %)	47 (2.45 %)	3 (2.16 %)	2 (1.98 %)	
Sex	2897					<0.001
Female	1009 (34.8 %)	120 (22.4 %)	846 (40.4 %)	34 (21.7 %)	9 (8.26 %)	
Male	1746 (60.3 %)	280 (52.3 %)	1243 (59.3 %)	123 (78.3 %)	100 (91.7 %)	
Mixed	142 (4.9 %)	135 (25.2 %)	7 (0.33 %)	0 (0.00 %)	0 (0.00 %)	
Weekend	3257					0.005
No	1507 (46.3 %)	360 (51.7 %)	1023 (44.8 %)	67 (40.9 %)	57 (49.6 %)	
Yes	1750 (53.7 %)	336 (48.3 %)	1259 (55.2 %)	97 (59.1 %)	58 (50.4 %)	
Summer	3257					0.427
No	2876 (88.3 %)	617 (88.6 %)	2005 (87.9 %)	148 (90.2 %)	106 (92.2 %)	
Yes	381 (11.7 %)	79 (11.4 %)	277 (12.1 %)	16 (9.76 %)	9 (7.83 %)	

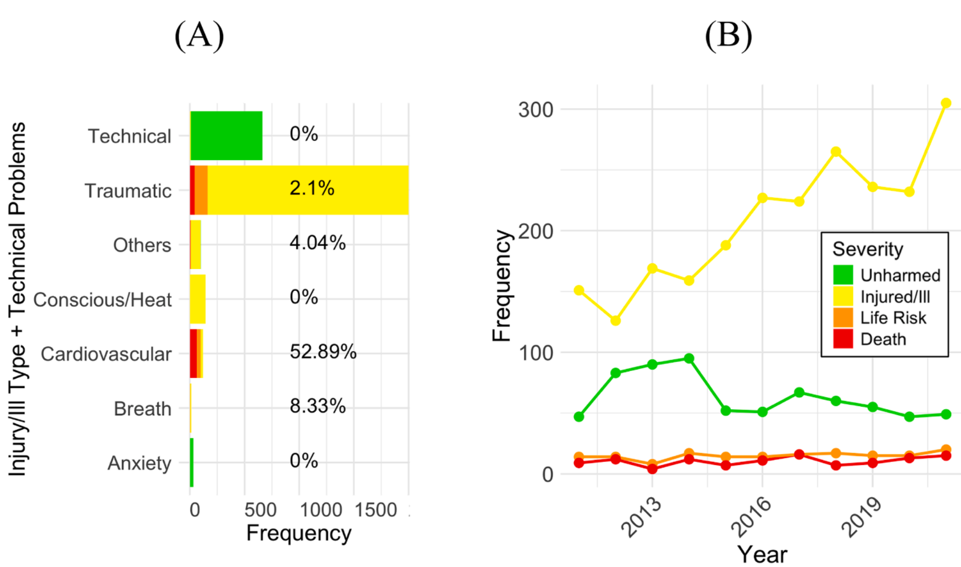

Fig. 1. (A) Severity of injury or ill by type including technical problems as cause. Percentages in the figure refer to the death rate. (B) Yearly frequency of accidents by severity of the outcome.

Table 4 shows the goodness-of-fit comparison between models. Accident-related models showed better fit than time-related variables and explained more variation in accident severity. Mixed models, improved the fit and the amount of explained variance, however adding cross fold interactions did not improve the fit significantly. These results aligned with the LR test were mixed models differed significantly from the accident-related model ($\chi^2 = 18.11,\ p < 0.001$) and the time-related model $\chi^2 = 209.89,\ p < 0.001$), while the mixed model with cross fold interactions did not differ from the model without cross fold interactions ($\chi^2 = 6.25,\ p = 0.3958$). Accordingly, the mixed model without cross fold interactions was selected.

Supplementary material S7 shows the residuals and influential points analysis. Overall, 194 observations exceeded both cutoffs and were deleted. They were mainly unharming accidents (189, 97.4 %), adequate equipment (162, 83.5 %) and increased climbing (23.7 %) or gathering (6.19 %) accidents compared to the whole sample.

Table 5 shows the coefficients for the final model with a non-proportional odds assumption and excluding poor fit and influential observations ($n = 2091$). The a Nagelkerke pseudo-$R^2$of 0.12, indicating a discrete to moderate explanatory power. The intercepts show that the unharmed to injured/ill threshold was statistically non-significant ($\beta_{\text{Unharmed/Injured-Ill}} = -0.04,\ p = 0.9148$) although the thresholds

Table 3
Absolute and relative frequency of causes of rescue and type of injury/ill. In Italics, traumatic accident causes by Severity. The most relevant outcomes are in boldface. TBI: Traumatic Brain Injury.

	Unharmed	Injured/Ill	Life Risk	Death	Overall
Technical problems	654 (95 %)	9 (0.5 %)	0 (0 %)	0 (0 %)	663 (21.59 %)
Anxiety	32 (5 %)	0 (0 %)	0 (0 %)	0 (0 %)	32 (1.04 %)
Breath	0 (0 %)	10 (0.5 %)	1 (1 %)	1 (1 %)	12 (0.39 %)
Cardiovascular	0(0 %)	23 (1 %)	34 (21 %)	64 (57.5 %)	121 (3.94 %)
Conscious/heat	0 (0 %)	145 (7 %)	0 (0.00)	0 (0 %)	145 (4.72 %)
Others	2 (0 %)	87 (4 %)	6 (4 %)	4 (4 %)	99 (3.22 %)
Traumatic	0 (0)	1835 (87 %)	122 (75 %)	42 (37.5 %)	1999 (65.09 %)
Fatal Falls	–	0 (0 %)	87 (71 %)	38 (29 %)	125
TBI	–	140 (81.9 %)	27 (15.8 %)	4 (2.3 %)	171
Fracture	–	761 (99.5 %)	4 (0.5 %)	0 (0 %)	765
Hemorrhage	–	4 (50 %)	4 (50 %)	0 (0 %)	8
Dislocation	–	181 (100 %)	0 (0 %)	0 (0 %)	181
Sprain	–	354 (100 %)	0 (0 %)	0 (0 %)	354
Wound or scratch	–	110 (100 %	0 (0 %)	0 (0 %)	110
Contusion	–	241 (100 %)	0 (0 %)	0 (0 %)	241
Muscular	–	44 (100 %)	0 (0 %)	0 (0 %)	44

Table 4
Goodness of fit (AIC, deviance and LogLikelihood) and variance explained (Nagelkerke pseudo$\boldsymbol{R}^2$) by the different models. They were ordered by increase of complexity and likelihood ratio (LR) test comparisons are included at the bottom.

Model description	AIC	Deviance	LogLik	Nagelkerke R^2
Time variables[a]	3532.48	3500.48	−1750.24	0.034
Accident-related variables[b]	3380.51	3338.51	−1669.26	0.121
Mixed Model	3358.58	3290.58	−1645.29	0.146
Mixed Model with cross fold interactions	3364.33	3284.33	−1642.17	0.149

LR Test: **Time vs Mixed** χ^2= 209.89, $p < 0.001$; **Accident-related vs Mixed** χ^2= 18.11, $p < 0.001$; **Mixed vs Mixed with crossfold interactions** χ^2= 6.25, p = 0.3958.

[a] No significant interaction was found.

[b] Contains the significant interactions.

for more severe categories were significant ($\beta_{\text{Injured−Ill/Life Risk}} = 4.451$, $p < 0.001$; $\beta_{\text{Life RIsk/Death}} = 5.55$, $p < 0.001$). The altitude odds ratios indicated very minimal effects on injury severity, but these effects were statistically significant with slight negative impacts on severity across all thresholds. Regarding sex, males had lower odds (0.72 times) of being in a less severe injury category compared to females (β= −0.33, p = 0.0107), suggesting that males were more prone to severe injuries. When comparing activities to hiking, the model showed that snow activities (β = −1.19, p = 0.5553), climbing (β =0.22, p = 0.5282) and canyoning (β = 0.02, p = 0.9889) had a similar relationship with severity. On the other hand, gathering (β = −2.51, $p < 0.001$), mountain biking (β =−1.48, $p < 0.001$) and other cultural activities (β =−1.45, $p < 0.001$) were at statistically significant lower odds of being in a less severe category.

Participation in group activities significantly decreased the odds (0.13 times) of being in a lower severity category compared to solo activities (β = −2.03, $p < 0.001$), suggesting more severe injuries in group settings. None of the years from 2012 to 2021 showed significant differences in injury severity compared to the baseline year 2011. Injuries occurring during weekends had statistically significant lower odds (0.65 times) of being in a less severe category compared to weekdays (β = −0.43, p = 0.0097), indicating that more severe injuries happened on weekends.

The interaction between altitude and activity revealed that altitude and gathering had a statistically significant positive interaction (β = 0.00, $p < 0.001$. Also, the interaction between altitude and group composition was statistically significant (β = 0.00, $p < 0.001$), indicating that the effect of altitude on injury severity varies depending on whether the person was alone or in a group.

Discussion

The present work aimed to define a mountain accident victim vulnerability profile in Catalonia. We modelled the relationship between variables such as date, activity, group composition, sex of the victim, kind of injury, altitude or rescue duration at different levels of severity using an ordinal regression approach. This epidemiologic retrospective approach over a 11-year period approach was used to approximate the latent continuous distribution of severity with the natural ordered responses. Overall, the results of the descriptive and the ordinal regression analyses were mostly aligned with previous literature.

Major victim profile

As expected, the main profile comprised being hiker, climber and mountain biker, but not canyoner as in past research [5,6]. We also found that males were the most affected compared with females [6, 12–14]. Traumatic injuries emerged as the primary concern, with fractures standing out as the most prevalent type, followed closely by sprains and contusions. Regarding time variables, which were related to cultural and socioeconomic factors, the results partially aligned with past research, since during weekend there was an increased number of accidents but not during summer vacation as suggested by previous studies [5–7,11,13].

Severity victim profiles

At the highest levels of severity, fatal falls accounted for the most part of fatal accidents. However, cardiovascular issues associated with the largest death rate (55 %). Traumatic injuries, stood out at low to severe outcome levels. Finally, technical problems such as being unable to continue a via ferrata, getting the ropes stuck during a rappel after a climbing route, or getting caught in the dark without a headlamp, were the leading cause of incidents resulting in no physical harm, emphasizing the need for enhanced readiness skills among outdoor enthusiasts. Mountain biking, gathering (mainly mushrooms), and other cultural activities were linked to higher injury severity compared with hiking. Gathering and cultural activities such as hunting were often practiced by older men who typically endure an increased cardiovascular risk [16,21, 22]. Finally, mountain biking accidents were linked to traumatic events derived from the potential of high energy impacts [41].

The interaction between altitude with specific activities revealed nuanced influences. Gathering and climbing activities showed a slight reduction in injury severity with increased altitude, which may be related with a reduced practice at higher altitude. Group composition also interacted in the same way with lessened risk at higher altitudes. Other significant factors affecting injury severity included sex, group composition, time of year, and whether the activity took place on a

Table 5
Coefficients of the Mixed Variables Model with non-proportional Odds assumption. Model fit: Deviance = 2650.091, Residual d.f = 6239, LogLikelihood = −1325.05, ***Nagelkerke* pseudoR^2** = 0.12. OR = Odds ratio, S.E = Standard Error, CI = Confidence Interval. The most relevant outcomes are in boldface.

Variables	Predictor	OR	β	95 % CI	S.E	Z	p
Intercepts	Unharmed:Injured/Ill	–	−0.04	(−0.71, 0.63)	0.34	−0.11	0.9148
	Unharmed:Life Risk	–	4.45	(3.67, 5.24)	0.40	11.16	<0.001
	Unharmed:Death	–	5.55	(4.70, 6.40)	0.43	12.79	<0.001
Altitude	Altitude:Unharmed	*Reference*					
	Altitude: Injured/Ill	1.00	−0.00	(−0.00, −0.00)	0.00	−4.05	<0.001
	Altitude:Life Risk	1.00	−0.00	(−0.00, −0.00)	0.00	−2.67	0.0077
	Altitude:Death	1.00	−0.00	(−0.00, −0.00)	0.00	−3.12	0.0018
Sex	Female	*Reference*					
	Male	0.72	−0.33	(−0.58, −0.08)	0.13	−2.55	0.0107
Activity	Hiking	*Reference*					
	Snow	0.30	−1.19	(−5.16, 2.77)	2.02	−0.59	0.5553
	Gathering	0.08	−2.51	(−3.83, −1.19)	0.67	−3.72	<0.001
	Climbing	1.25	0.22	(−0.47, 0.91)	0.35	0.63	0.5282
	Canyoning	1.02	0.02	(−2.23, 2.26)	1.15	0.01	0.9889
	Mountain Biking	0.23	−1.48	(−2.04, −0.91)	0.29	−5.12	<0.001
	Others	0.23	−1.45	(−2.16, −0.75)	0.36	−4.04	<0.001
Group	Alone	*Reference*					
	Group	0.13	−2.03	(−2.55, −1.50)	0.27	−7.49	<0.001
Year	2011	*Reference*					
	2012	1.17	0.15	(−0.48, 0.79)	0.33	0.47	0.6349
	2013	1.59	0.47	(−0.15, 1.08)	0.31	1.48	0.1378
	2014	0.92	−0.09	(−0.69, 0.52)	0.31	−0.28	0.7806
	2015	1.27	0.24	(−0.36, 0.84)	0.31	0.78	0.4343
	2016	0.82	−0.20	(−0.77, 0.37)	0.29	−0.69	0.4914
	2017	0.98	−0.02	(−0.58, 0.54)	0.29	−0.07	0.9447
	2018	0.96	−0.04	(−0.59, 0.52)	0.28	−0.13	0.8984
	2019	1.14	0.13	(−0.44, 0.70)	0.29	0.45	0.6535
	2020	1.15	0.14	(−0.43, 0.71)	0.29	0.48	0.6290
	2021	1.12	0.11	(−0.43, 0.65)	0.28	0.40	0.6868
Weekend	Yes:Unharmed	*Reference*					
	Yes:Injured/Ill	0.65	−0.43	(−0.76, −0.10)	0.17	−2.59	0.0097
	Yes:Life Risk	1.01	0.01	(−0.28, 0.31)	0.15	0.09	0.9244
	Yes:Death	1.09	0.08	(−0.34, 0.51)	0.22	0.39	0.6993
Altitude:Activity	Altitude:Hiking	*Reference*					
	Altitude: Snow	1.00	0.00	(−0.00, 0.00)	0.00	0.35	0.7247
	Altitude: Gathering	1.03	0.00	(0.00, 0.00)	0.00	4.34	<0.001
	Altitude: Climbing	1.00	−0.00	(−0.00, 0.00)	0.00	−1.80	0.0726
	Altitude: Canyoning	1.00	−0.00	(−0.00, 0.00)	0.00	−0.12	0.9065
	Altitude: Mountain Biking	1.00	0.00	(−0.00, 0.00)	0.00	1.42	0.1560
	Altitude:Others	1.00	0.00	(−0.00, 0.00)	0.00	0.27	0.7877
Altitude:Group	Altitude:Alone	*Reference*					
	Altitude:Group	1.00	0.00	(0.00, 0.00)	0.00	3.44	<0.001

weekend. Regarding sex, and as expected, males endured increased severity. However, female proportion at lower levels of severity were higher than male because of being more prone to suffer mild/moderate traumatisms [16]. In contrast, groups led to more severe accidents than solo victims (Table in Supplementary material S6).

Regarding time patterns, mild and moderate accidents were more frequent during weekend as reported in previous studies [5,7]. Over the 2011–2021 period, the yearly number of accidents increased but only in mild and moderate accidents.

Accounting for severity, the ordinal regression models explained discrete variance in accident severity. It was somehow expected since accidents proximal variables such as psychological and physical factors, group dynamics, environmental factors or objective hazards could not be identified in the phone operators' transcriptions. For an extensive review of the large amount and levels of variables involved in accidents see Vanpoulle et al. [42].

Finally, while at higher levels of severity (life risk and fatal), the thresholds were strongly defined, the lower severity thresholds (unharming and mild/moderate accidents) did not show statistical significance leading to difficulties on comparing severity at those levels. Nonetheless, non-harming accident derives from specific factors such as lack of technical skills, fatigue or losing the way in contrast with harming accidents where common causes are suffering mild fractures and sprains.

Limitations and future research

Regardless the extensive work and the careful depuration of data and statistical models, the present study involved some limitations. First, data related to the health outcome, its severity, and sex and group variables, were extracted from transcriptions which were written by emergency phone operators under stressful conditions. Also, available information available was collected by different phone operators and communications were established by rescuers from different call centers and fire stations. However, most of accident reports follow a standardized procedure to communicate the information to avoid misunderstandings and improve consistency. Second, diagnoses were made by the rescue teams without formal medical advanced diagnostic tools. Nevertheless, rescuers are often technicians, and they all have first aid certification and medical skills, which is appropriated to provide a reliable preliminary diagnosis. Third, there was an estimated classification error of 7 % in the type of rescue operation based on the contrast of the text report and the category assigned. Moreover, approximately half of the accidents had to be deleted due to missing data losing the chance to conduct a reliable estimate of the prevalence or some of the relative frequencies. Fourth, the severity levels in present study were four instead of the seven levels in the IIC – UIAA MedCom Score [27]. Due to the insufficient details provided in the operation reports, the full spectrum of severity remains to be further explored. In addition, most part of accident location characteristics and situational factors were missing which might provide a more accurate prediction of severity and kind of accidents.

Future research should prioritize a detailed examination of the spatiotemporal distribution of accidents within natural protected areas, providing more information from scenario and meteorology circumstances. This may involve identifying and analyzing accident hotspots to guide the strategic placement of informative panels and protective barriers, thereby enhancing safety measures for visitors. Also, future studies focused on severity should measure larger severity levels according to its continuous distribution.

Conclusions

The outcomes from this study were mostly aligned with foreign literature, however the model explained modest variation suggesting that more proximal factors should be accounted. The present study contributes to define the first vulnerability profile of the mountain accident victims in Catalonia. It has also contributed to the body of research by capturing more severity variability of mountain accidents outcome.

CRediT authorship contribution statement

Albert Martínez: Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Formal analysis, Data curation. **Angel Blanch:** Writing – review & editing, Writing – original draft, Software, Conceptualization. **Carles Comas:** Writing – review & editing, Writing – original draft, Software, Conceptualization.

Declaration of competing interest

There were no conflicts of interest/competing interests.

Ethics statement

This study was conducted using anonymized data obtained from the official records of the Catalan Fire Department (Direcció General d'Extinció, Prevenció d'Incendis i Salvaments – DGPEIS, which is responsible for mountain rescue operations in Catalonia. The dataset comprises mountain rescue operations between 2011 and 2021 and was used solely for research purposes aimed at improving public safety and informing prevention strategies.

All data were fully anonymized prior to analysis to protect the privacy and confidentiality of individuals involved in rescue operations. No identifiable personal information was accessed or used. The study protocol adhered to the ethical guidelines for research involving human data and was carried out in accordance with the principles of the Declaration of Helsinki.

Given the nature of the data and its anonymization, the study did not require formal approval from an ethics committee.

Acknowledgements

We would like to thank the Directorate-General of Fire prevention, Extinction and Rescue (DGPEIS) of the Generalitat de Catalunya for providing data on rescues. This research was performed within the Catalonian Consolidated Research Groups 2021 SGR 01423 and 2021 SGR 00434.

Declarations

No funding was received for conducting this study.

The study was conducted in accordance with ethical standards.

The code is available from the corresponding author on request.

The data is available upon request from the corresponding author, pending permission from DGPEIS.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2025.112672.

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