Forensic Science International: Reports 4 (2021) 100239

Contents lists available at ScienceDirect

Forensic Science International: Reports

journal homepage: www.sciencedirect.com/journal/forensic-science-international-reports

General Forensics

Fatalities associated with ski touring and freeriding: A retrospective analysis from 2001 to 2019

Martin Gross *, Christian Jackowski, Corinna A. Schön

Institute of Forensic Medicine, University of Berne, Berne, Switzerland

ARTICLE INFO

Keywords:
Mountaineering skiing
Wilderness medicine
Sports science
Winter sports
Avalanches

ABSTRACT

Introduction: Winter sports off the marked slopes are becoming more popular. All sports in uncontrolled and mountainous terrain are combined with risks and claim fatalities every year. This study investigates the circumstances, causes and epidemiological aspects of fatalities of the two most common winter sports outside prepared slopes.

Methods: This retrospective study deals with off-slope fatalities reported to the authorities in the Canton of Berne, Switzerland, between 2001 and 2019. The cases were examined for various parameters and statistically evaluated. Ski touring was compared with freeriding.

Results: Fifty-nine cases were examined. The male/female ratio was 4/1. Freeriders were significantly younger than ski tourers when they died (27 ± 9 y vs. 39 ± 15 y, $P = 0.005$). In 8 cases the cause of death was classified as natural, in 51 cases an accident was the reason for the fatality. The most frequent incident was an avalanche (63% of all cases). Freeriders had significantly more lacks in their equipment than ski tourers (86 vs. 50%, $P = 0.013$).

Conclusion: Our results indicate that fatally injured freeriders were significantly younger, less equipped and prepared than ski tourers when skiing uncontrolled winter backcountry. Prevention programs should therefore focus on young and unexperienced freeriders who decide to leave the marked slope in ski areas without any preparations.

1. Introduction

Winter sports are very popular in Switzerland, especially the popularity of ski-/snowboard touring and freeriding is increasing [1]. Ski touring is characterized by climbing a mountain without mechanized assistance by using special skis or snowshoes and brawn and the following descent away from controlled slopes with skis or a snowboard [2]. Freeriding is defined by using the infrastructure of a ski area for the ascent (e. g. cable car or gondola) and descending on skis or a snowboard away from the marked slopes. Marked slopes are defined as downhill routes that are managed by a mountain railway company. In addition, they are frequently controlled by specialists and secured against alpine hazards. In the Alps, that includes all downhill routes on which the cable car company can be held liable in case of bad signposting or missing fall protection [2]. In Switzerland, it is easy to cross the boundaries from marked slopes of ski resorts to the backcountry for freeriding.

Between 2011 and 2015, on average 34 people died each year while skiing and snowboarding in Switzerland. Eighty-five percent of these fatal accidents occurred off the marked slopes [3]. In the years 2000–2015, the Swiss Council for Accident Prevention recorded 8–19 annual fatalities in freeriders [3]. The Swiss Alpine Club (SAC) recorded 27 fatal ski touring incidents and 10 fatal freeride incidents in Switzerland just in 2019 alone. However, there was no trend in those numbers, so that the fluctuations were explained by meteorological variations such as snow and weather conditions on occurrence of avalanches [3].

Naturally the uncontrolled winter backcountry bears hazards, such as avalanches or crevasses and voluntary human exposure to these hazards turns them into uncontrollable risks of injury and/or hypothermia [4,5].

Avalanches account for approximately 20 fatalities per year in Switzerland [2], with a constant avalanche risk per ski tour day between 1999 and 2010 [6].

Among ski tourers, falls are the most common cause of death especially in steep, rocky or icy terrain [7]. Falls into glacial crevasses were fatal in 16 ski touring and 14 freeriding accidents in the Swiss alps

* Correspondence to: Institute of Forensic Medicine, Bühlstr. 20, CH - 3012 Berne, Switzerland.
E-mail address: martin.gross@students.unibe.ch (M. Gross).

https://doi.org/10.1016/j.fsir.2021.100239
Received 18 August 2021; Received in revised form 11 October 2021; Accepted 12 October 2021
Available online 14 October 2021

between 2000 and 2010 [8]. Beside environmental hazards, behavioral errors such as skill overestimation and errors in decision-making account for a significant number of fatal accidents [9].

In a recent review, Faulhaber pointed out, that most studies on mountain winter accidents focus on alpine skiing and/or avalanches [10]. There are no studies analyzing fatal accidents in ski touring and freeriding. In order to design effective programs to prevent fatal mountain sport accidents [9], exact definitions of characteristics and causes of the accidents are required [11].

In extreme sports, forensic data may be critical to understand the real cause of death and investigate all the factors of an accident, including any human error, drugs, medication or alcohol consumption and any relevant pre-existing diseases. Therefore, a knowledge of fatality rates and accident dynamics is essential for sports and forensic medicine specialists. Moreover, epidemiological and autoptic data relative to extreme sport fatalities may assist future preventive research, the development of safety systems, guidelines and protective clothing [12].

We therefore analyzed circumstances, causes and epidemiological aspects leading to a fatality during ski touring and freeriding in this retrospective study.

2. Methods

This retrospective study analyzes fatal winter sport accidents occurring off marked slopes in the canton of Berne in Switzerland between 2001 and 2019. We differentiated between ski touring and freeriding. The ascent with snowshoes or a split board and the subsequent descent with a snowboard ("snowboard touring") was included in the group of ski touring. Snowshoeing, winter mountaineering or ice fall climbing were not included because of the different nature of those sports and the associated risk profiles.

The ski touring and freeride fatalities for this period were determined by using the databases of the SAC, the public prosecutor's office of the canton of Berne and the Institute of Forensic Medicine, University of Berne. The following parameters were taken from the corresponding investigation files of the responsible public prosecutor's offices. The responsible departments of public prosecution authorized the use of the anonymized case data. Due to the retrospective nature of the study no further ethics approval was necessary.

2.1. Personal data

Sex, age, origin, experience in ski touring or freeriding (having experience yes or nor) were studied. Experience was classified as follows: experience was defined as an education in mountain sports received by the SAC or a similar organization, a regular practice of either sports for several years and several times per year or being a mountain guide or a person in a comparable function.

2.2. Forensic and medical data

Kind of forensic investigation of the body (autopsy defined as the opening of the body with detailed examination of the soft tissue, skeleton and inner organs of the three cavities skull, thorax and abdomen combined with a prior postmortem radiological examination or only external examination of the body without postmortem radiology), cause of death, manner of death (accident or natural), results of toxicological investigations (positive result, negative result or not given) and previous illnesses (yes or no) were measured.

2.3. Accident circumstances

Tour type (ski touring or freeriding), altitude of the event (over 1800 m or below), cause of the event, equipment (wearing of an avalanche transceiver, avalanche airbag and helmet), fall height in cases of a fall and tour planning (indications of a planning or no indications) were measured. In this study, tour planning is defined as to deal with the hazards in the uncontrolled winter backcountry. There were indications of tour planning if there was information about consulting the avalanche and/or weather forecast, measuring the slope inclination, planning the route on a map, defining returning points and times and considering special hazards like crevasses or exposed areas.

The mortality index (number of deaths per number of accidents) is given [7] since the mortality risk (number of deaths in all off piste athletes) can not be calculated [7].

To calculate the mortality index the accident register of the SAC was used. In this register, all mountain emergencies related to ski touring or freeriding were included. The term "mountain emergency" includes all incidents in which mountaineers requested the assistance of the mountain rescue services. Near-misses were also included. An incident that nearly resulted in death or serious injury was subjectively defined as a near-miss [13]. The incident was mostly averted by mountain rescue. In this context, near-misses are also counted among accidents.

3. Statistics

Data were analyzed using IBM SPSS software version 27. Most results were presented as frequencies in parentheses. The total frequency (in percent, ski tourers and freeriders together) is given first; followed by the percentage of ski tourers versus the percentage of freeriders. Frequencies of categorizable variables were compared by the chi-square test or Fisher's exact test. For continuous variables, the *t*-test was performed. For means, the standard deviation (mean ± SD) was given. Results were considered statistically significant if the P-value was below 0.05.

4. Results

The records from the Institute of Forensic Medicine of the University of Berne indicated a total of 62 fatalities during ski touring or freeriding activities in the canton of Bern between 2001 and 2019. We were able to investigate 59 cases. In 3 cases the files were missing. On forensic investigation, the cause of death was classified as natural in 8 cases (14%) and accident related in 51 cases (86%). That death was natural was confirmed by autopsy in one of eight cases. Thirty-five (69%) fatal accidents occurred during ski touring and 16 (31%) during freeriding.

The mean age of all deceased was 36 ± 15 years. Freeriders were significantly younger than ski tourers at the time of death (39 ± 15 y vs. 27 ± 9 y, $P = 0.005$). In both groups, far more men came to death than women (proportion of men: 80%; 83% vs. 75%). The proportion of Swiss citizens predominated foreigners in both groups (69%; 74% vs. 56%).

Thirteen cases (25%) were autopsied. In the other 38 cases (75%), only an external inspection of the body was carried out. The causes of death (Table 1) were either confirmed by an autopsy or mostly suspected by the external inspection. In very few cases, a toxicological study was performed (14%; 17% vs. 6%). Results were negative in all cases.

Types of events are detailed in Table 2. Most avalanche victims died of asphyxiation (69%; $P < 0.001$) and most fall-related victims of traumatic brain injury (47%; $P < 0.001$). Of note, fall height was much higher in ski touring than in freeriding (299 ± 253 m vs. 50 ± 24 m; $P = 0.021$).

Utilization of safety equipment (avalanche transceiver, airbag and helmet) was significantly different between ski tourers and freeriders (Table 3). In 11 cases the use of a helmet could not be determined. In cases where victims died from traumatic brain injuries, no accumulation of traumatic brain injuries could be found among non-helmet wearers (44% helmet worn vs. 44% helmet not worn, 1 case unknown).

Ski tourers and freeriders with no experience had more lacks in their equipment (75% vs. 23%, $P = 0.004$). The accident victims with no evidence of tour planning had often a shortage of equipment (67% vs. 15%, $P = 0.001$). However, there was no significant age difference between well and poorly equipped victims (36 y vs. 34 years).

Table 1
Causes of death in the two investigated groups. The values are given in absolute and relative frequencies.

	Total (n = 51)	Cause of death confirmed by autopsy (n = 13)	Ski Touring (n = 35)	Freeriding (n = 16)	P-value
Asphyxiation (n) (%)	24 (47)	10 (42%)	18 (51)	6 (38)	0.384
Traumatic brain injury (n) (%)	9 (18)	2 (22%)	5 (14)	4 (25)	0.436
Blood loss (n) (%)	5 (10)	0 (0%)	3 (9)	2 (13)	0.643
Multiple trauma (n) (%)	5 (10)	0 (0%)	3 (9)	2 (13)	0.643
Neck fracture (n) (%)	4 (8)	0 (0%)	3 (9)	1 (6)	1.000
Hypothermia (n) (%)	2 (4)	1 (50%)	2 (6)	0 (0)	1.000
Heart failure (n) (%)	1 (2)	0 (0%)	0 (0)	1 (6)	0.314
Unclear (n) (%)	1 (2)	0 (0%)	1 (3)	0 (0)	1.000

Table 2
Type of event in the two investigated groups. The values are given in absolute and relative frequencies.

	Total (n = 51)	Ski Touring (n = 35)	Freeriding (n = 16)	P-value
Avalanche (n) (%)	32 (63)	24 (69)	8 (50)	0.228
Fall from height (n) (%)	17 (33)	9 (26)	8 (50)	0.115
Fall into a crevasse (n) (%)	2 (4)	2 (6)	0 (0)	1.000

Table 3
Safety equipment components in the two investigated groups. The values are given in absolute and relative frequencies.

	Total (n = 51)	Ski touring (n = 35)	Freeriding (n = 16)	P-value
Avalanche transceiver (n) (%)	38 (75)	30 (86)	8 (50)	0.013
Helmet (n) (%)	18 (35)	10 (29)	8 (50)	0.327
Avalanche airbag (n) (%)	2 (4)	2 (6)	0 (0)	0.483

In 15 cases, there were no data on any tour planning and in 7 cases the skiers experience could not be elucidated. Ski tourers planned their tour more frequently than freeriders (51% vs. 25%, $P = 0.127$) and no planning of the tour at all was found in 63% of all freerides as compared to 11% in ski tourers ($P < 0.001$). No difference was found regarding the experience in both groups (experienced 54% vs. 50%).

The SAC recorded a total of 813 snow sports accidents off marked slopes in the canton of Berne in the years 2004–2019. Two hundred and seven accidents occurred during freeriding and 606 accidents during ski touring. Based on those data the mortality index in this series was 7.2% while freeriding and 6.6% during ski touring.

5. Discussion

People who ski away from the marked slopes face a higher risk of dying in an accident than those who ski on the marked slopes [14].

In our study, the mortality index of an accident while freeriding was 7.2% and 6.6% in ski touring. The German Alpine Association reported 165 mountain emergencies from their members related to ski touring in 2016/17; six people lost their lives [15]. Based on this information, this represents a mortality index of 3.6%. In a French study, a mortality index of 8% for ski touring was reported [16].

Comparing the data with other mountain sports shows that mortality indexes are similar or even higher. The mortality index for ski touring and freeriding is higher than the mortality index for alpine climbing with 6% (13/220 injured athletes) [17] and significantly higher than the mortality index found for mountain air-sports including paragliding, hang gliding and speed flying with 2.5% (42/1637 injured athletes) [18].

The average age of ski tourers, snowboard tourers and snowshoers in Switzerland is 49 years [2]. The Swiss Council for Accident Prevention expected that the average age for freeriding is significantly lower than for ski touring [2]. A significant difference between these two groups was also found in the data collected.

In both groups, more men than women died. This does not correspond with the percentage of women who practice ski touring in Switzerland. It is estimated that 53% of all people who practice sports in uncontrolled winter backcountry are women [2]. A possible reason for the higher proportion of men among fatalities could be a higher risk behavior of men [19].

Although only complete autopsies and toxicological examinations are able to delineate all injuries and the cause of death as well as the failure of certain safety equipment, the autopsy rate in this and other studies on mountain fatalities [20,21] remains low. In a study of 1060 deaths, of which 1023 were autopsied, there was no concordance between the external inspection and autopsy confirmed diagnosis in 45% of men and 48.8% of women [22,23].

Toxicological investigations were even less frequently performed (17% vs. 6%) than autopsies. Specifically, the use of alcohol is a recognized cause of accidents in adventure and extreme sports. Studies, especially from air-sports, have shown that accidents occur increasingly after alcohol or drug abuse [24,25]. Exposure to drugs and alcohol can have a relevant impairment of motor and psychological abilities in winter sports [21], which suggests an increased likelihood of accidents in the presence of alcoholization. Toxicological investigations are the only way to clarify alcohol or drug associated psychomotor impairment as potential cause of death. Furthermore, they might furthermore be of significant legal importance.

The cause of death was not different between the two groups, with asphyxiation being the most frequent cause of death in this study. This was clearly related to avalanches. Also in a number of other studies, asphyxiation was the most common cause of death in avalanches [26–29].

In this study, traumatic brain injury as cause of death was caused by falls. Accidents caused by falls are a frequent incident in mountain sports [30,31]. In these cases, traumatic brain injury represents the most common cause of death [20].

The most frequent cause of a fatal accident in our study was an avalanche (63%). Even in mechanically aided skiing, avalanches contributed to the overall risk of death in 77% in a Canadian trial [5]. Interestingly, even though the number of people in uncontrolled winter backcountry increased between 1977 and 2006, Harvey et al. were able to demonstrate that the number of victims completely buried by an avalanche remained constant [32]. Even more, they found a decrease in the mortality rate of avalanche accidents due to better training and utilization of safety equipment and improved information on snow conditions and avalanche situations [32].

In our study, ski tourers were better equipped than freeriders, by wearing significantly more avalanche transceivers. Avalanche transceivers reduce mortality significantly by shortening the average burial time and increasing spontaneous and successful rescues by companions [33]. An Austrian study demonstrated that the avalanche transceiver plays a minor role in freeriding, as freeriders are more often rescued by organized rescue than by companions [33]. Immediately available rescue dogs and helicopters of the Austrian Mountain Rescue Service were found to have favorable survival rates even for freeriders without

avalanche transceivers [33]. When freeriding, the awareness of the danger off the marked slope is sometimes not present in view of already existing tracks or the decision to leave the marked slope is made spontaneously [2]. This could also be a reason for a lack of equipment in freeriding.

Safety equipment further includes avalanche airbags. They may prevent a total burial and thereby minimize fatal asphyxiation when caught in an avalanche [34]. The limiting factor of avalanche airbags is timely inflation. In prior studies, avalanche airbags reduce the mortality risk in avalanches only by 8–16% [35,36]. Also in the present study, avalanche airbags were used only in two fatal avalanche accident, indicating either a successful prevention of a fatal outcome or the scarse use. Nevertheless, avalanche airbags remain important as one of few avalanche emergency devices available [36].

Also, the fact that only about one third of all fatally injured athletes in our study were wearing a helmet does not reflect the observation on marked slopes. Here, the rate of helmet usage is 92%, at least in Switzerland [3]. That high rate was achieved through extensive prevention campaigns [37]. For this reason, it could be suspected that prevention campaigns for wearing helmets, which specifically target winter sports enthusiasts next to the marked slopes, could increase the rate of helmet usage.

Nevertheless, no accumulation of non-helmet wearers and traumatic brain injury was found. Whether wearing a helmet could have minimized the number of fatal accidents cannot be determined from the available data. Non-fatal head injuries can be reduced by wearing a helmet, but that does not reduce the overall death rate when skiing and snowboarding on piste [38]. The fact that wearing a helmet reduces head injuries can also be seen in other mountain sports such as mountain biking [39,40].

In 11 cases, it was unclear whether a helmet was worn or not. In events like an avalanche or a fall, it is possible that a worn helmet was lost during the event and that it was not found during the rescue or the investigation of the scene itself. Regarding the avalanche airbag and the avalanche transceiver, the loss of this kind of equipment is rather unlikely as long as it was worn correctly.

Freeriders were also less well prepared for the tour than the ski tourers. One explanation for this result could be that freeriding is a more spontaneous decision than ski touring [2]. In Switzerland, it is easy to leave marked slopes and follow prior tracks in unmarked terrain. Therefore, poorly equipped alpine skiers may easily decide to freeride on a snow sports day.

6. Limitations

There are a number of limitations in this study, mostly attributable to the retrospective nature and the data retrieval from databases designed for other purposes than forensic research. Therefore, when comparing data bases from the public prosecutor's office with other data bases we found complete cases of single data points that might have been interesting for our analysis missing. This was due to different sources reporting the cases, regulations on reporting or contents of collected information.

The nature of extreme sports in general, often practiced alone or in small groups in remote places, adds challenges to data collection. This is a common problem when studying adventure/extreme sports, hence the retrospective nature of many such studies [41].

Also only cases of the last 20 year period could be analyzed, since files of the public prosecutor's office are kept only for a maximum of 20 year in the canton of Berne, while a longer time interval could have increased the number of cases.

Another limitation was the definition of certain parameters like level of experience or tour planning.

Also causes of death were not confirmed by autopsy in all cases, but were the result of an external examination of the body. Therefore higher autopsy rates are essential for future investigations of the cause of death in ski tourers and freeriders.

7. Conclusion

This study showed that fatally injured freeriders were significantly younger, poorly equipped and less prepared than ski tourers. Since lack of equipment and preparation are simply avoidable risk factors for a fatal accident, prevention programs could be useful. These should point out the importance of good preparation and safety equipment in the uncontrolled winter backcountry and inform about the dangers (eg, avalanches) of spontaneously leaving the marked slopes. Prevention should be aimed in particular at young and unexperienced freeriders.

Prospective studies on preparation (tour planning, risk management, safety equipment) in ski touring and freeriding should be considered to obtain a general comparison of these two sports.

Performing an autopsy, as well as a toxicological examination in case of fatal accidents in the uncontrolled winter backcountry would be important, as their results may change the focus of prevention policies.

CRediT authorship contribution statement

Martin Gross: Conceptualization, Data curation, Methodology, Formal analysis, Investigation, Writing – original draft. **Christian Jackowski**: Writing – review & editing. **Corinna A. Schön**: Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank to the public prosecutor's office of the canton of Berne for providing the investigation reports and to the SAC for offering certain data.

Financial/material support statement

None.

Disclosure statement

None.

References

[1] M. Lamprecht, R. Bürgi, H. Stamm, Sport Schweiz 2020: Sportaktivität und Sportinteresse der Schweizer Bevölkerung, Bundesamt für Sport BASPO, Magglingen, 2020.
[2] M. Walter, O. Brügger, Lawinenunfälle beim Touren- und Variantenfahren: Unfall-, Risiko- und Interventionsanalyse, bfu –Beratungsstelle für Unfallverhütung, 2012.
[3] G. Bianchi, O. Brügger, Unfallgeschehen beim Ski- und Snowboardfahren in der Schweiz: Unfallausmass, Risikoabschätzung und Entwicklung, bfu – Beratungsstelle für Unfallverhütung, 2016.
[4] G. Statham, Avalanche hazard, danger and risk – a practical explanation, in: Proceedings of the International Snow Science Workshop Whistler, Canada, 2008, pp. 224–227.
[5] M. Walcher, P. Haegeli, S. Fuchs, Risk of death and major injury from natural winter hazards in helicopter and snowcat skiing in Canada, Wilderness Environ. Med. 30 (3) (2019) 251–259, https://doi.org/10.1016/j.wem.2019.04.007.
[6] K. Winkler, F. Techel, Wie männlich ist der Lawinentod? DAV Panorama, 2017.
[7] M. Niedermeier, H. Gatterer, E. Pocecco, A. Frühauf, M. Faulhaber, V. Menz, J. Burtscher, M. Posch, G. Ruedl, M. Burtscher, Mortality in different mountain sports activities primarily practiced in the winter season—a narrative review, Int. J. Environ. Res. Public Health 17 (1) (2019) 259, https://doi.org/10.3390/ijerph17010259.

[8] M. Pasqiuer, P. Taffé, A. Kottmann, U. Mosimann, O. Reisten, O. Hugli, Epidemiology and mortality of glacier crevasse accidents, Injury 45 (11) (2014) 1700–1703, https://doi.org/10.1016/j.injury.2014.07.001.
[9] A. Chamarro, J. Fernández-Castro, The perception of causes of accidents in mountain sports: a study based on the experiences of victims, Accid. Anal. Prev. 41 (1) (2009) 197–201, https://doi.org/10.1016/j.aap.2008.10.012.
[10] M. Faulhaber, E. Pocecco, M. Niedermeier, G. Ruedl, D. Walter, R. Sterr, H. Ebner, W. Schobersberger, M. Burtscher, Fall-related accidents among hikers in the Austrian Alps: a 9-year retrospective study, BMJ Open Sport Exerc. Med. 3 (2017), 000304, https://doi.org/10.1136/bmjsem-2017-000304.
[11] S.C. Though, J.C. Butt, A review of 19 fatal injuries associated with backcountry skiing, Am. J. Forensic Med. Pathol. 14 (1) (1993) 17–21, https://doi.org/10.1097/00000433-199303000-00004.
[12] F. Felletti, Fatalities related to extreme aerial sports, in: G. Rutty (Ed.), Essentials of Autopsy Practice, Springer, Cham, 2019, https://doi.org/10.1007/978-3-030-24330-2_7.
[13] O. Mei-Dan, M.R. Carmont, E. Monasterio, The epidemiology of severe and catastrophic injuries in BASE jumping, Clin. J. Sport Med. 22 (3) (2012) 262–267, https://doi.org/10.1097/JSM.0b013e31824bd53a.
[14] J.S. Windsor, P.G. Firth, M.P. Grocott, G.W. Rodway, H.E. Montgomery, Mountain mortality: a review of deaths that occur during recreational activities in the mountains, Post. Med. J. 85 (1004) (2009) 316–321, https://doi.org/10.1136/pgmj.2009.078824.
[15] P. Randelzhofer, Bergunfallstatistik 2016/2017, Deutscher Alpenverein e. V. München, 2018.
[16] B. Soulé, B. Lefèvre, E. Boutroy, The dangerousness of mountain recreation: a quantitative overview of fatal and non-fatal accidents in France, Eur. J. Sport Sci. 17 (7) (2017) 931–939, https://doi.org/10.1080/17461391.2017.1324525.
[17] W.S. Bowie, T.K. Hunt, H.A. Allen Jr., Rock-climbing injuries in Yosemite National Park, West J. Med. 149 (2) (1988) 172–177.
[18] F. Feletti, A. Aliverti, M. Henjum, M. Tarabini, E. Brymer, Incidents and injuries in foot-launched flying extreme sports, Aerosp. Med. Hum. Perform. 88 (11) (2017) 1016–1023, https://doi.org/10.3357/AMHP.4745.2017.
[19] J.P. Byrnes, D.C. Miller, W.D. Schafer, Gender differences in risk taking: a meta-analysis, Psychol. Bull. 125 (3) (1999) 367–383.
[20] S. Zürcher, C.A. Schön, C. Jackowski, Circumstances and causes of death of hikers at different altitudes: a retrospective analysis of hiking fatalities from 2003–2018, Forensic Sci. Int. 310 (2020), 110252, https://doi.org/10.1016/j.forsciint.2020.110252.
[21] S.N. Kunz, T. Keller, C. Grove, S. Lochner, F. Monticelli, Tödliche Skiunfälle – eine gerichtsärztliche Übersicht am Beispiel des Landes Salzburg. Archiv für Kriminologie, Salzburg.
[22] D. Modelmog, Die Todesursachen in Görlitz 1986/87 - Ergebnisse der "Görlitzer Studie", Ber. Naturforsch. Ges. Oberlausitz. 3 (1994) 43–50.
[23] B. Madea, M. Rothschild, The post mortem external examination, Dtsch. Arzteblatt Int. 107 (33) (2010) 575–586.
[24] T. Rekand, The epidemiology of injury in hang-gliding and paragliding, Med. Sport Sci. 58 (2012) 44–56, https://doi.org/10.1159/000338581.
[25] F.W. Ast, G. Kernbach-Wighton, H. Kampmann, E. Koops, K. Püschel, H.D. Tröger, W.J. Kleemann, Fatal aviation accidents in Lower Saxony from 1979 to 1996, Forensic Sci. Int. 119 (1) (2001) 68–71, https://doi.org/10.1016/s0379-0738(00)00398-4.
[26] H. Brugger, B. Durrer, L. Adler-Kastner, On-site triage of avalanche victims with asystole by the emergency doctor, Resusciation 31 (1996) 11–16, https://doi.org/10.1016/0300-9572(95)00913-2.
[27] H. Brugger, B. Durrer, L. Adler-Kastner, M. Falk, F. Tschirky, Field management of avalanche victims, Resuscitation 51 (2001) 7–15, https://doi.org/10.1016/s0300-9572(01)00383-5.
[28] A. Weymann, Lawinenunfälle in den Schweizer Alpen, AO International, 2000.
[29] S. Rauch, K. Schenk, P. Paal, G. Strapazzon, H. Brugger, Avalanche emergency - update 2015: new findings call for new strategies, Notarzt 31 (2015) 301–305.
[30] T. Goodman, K. Iserson, H. Strich, Wilderness mortalities: a 13-year experience, Ann. Emerg. Med. 37 (3) (2001) 279–283.
[31] G.M. Curran-Sills, A. Karahalios, Epidemiological trends in search and rescue incidents documented by the Alpine Club of Canada from 1970 to 2005, Wilderness Environ. Med. 26 (4) (2015) 536–543, https://doi.org/10.1016/j.wem.2015.07.001.
[32] S. Harvey, B. Zweifel, Neue trends in der Lawinenunfallstatistik, Schweizer Alpen-Club, Die Alpen, 2008.
[33] M. Hohlrieder, P. Mair, W. Würtl, H. Brugger, LVS – eine (zwischen)bilanz, bergundsteigen, 2004.
[34] S.E. Mc Intosh, C.E. Little, T.D. Seibert, N.E. Polukoff, C.K. Grissom, Avalanche airbag post- burial active deflation—the ability to create an air pocket to delay asphyxiation and prolong survival, Resuscitation 146 (2020) 155–160, https://doi.org/10.1016/j.resuscitation.2019.11.023.
[35] H. Brugger, H.J. Etter, B. Zweifel, P. Mair, M. Hohlrieder, J. Ellerton, F. Elsensohn, J. Boyd, G. Sumann, M. Falk, The impact of avalanche rescue devices on survival, Resuscitation 75 (3) (2007) 476–483, https://doi.org/10.1016/j.resuscitation.2007.06.002.
[36] P. Haegeli, M. Falk, E. Procter, B. Zweifel, F. Jarry, S. Logan, K. Kronholm, M. Biskupič, H. Brugger, The effectiveness of avalanche airbags, Resuscitation 85 (9) (2014) 1197–1203, https://doi.org/10.1016/j.resuscitation.2014.05.025.
[37] M. Lamprecht, H. Stamm, Observatorium Sport und Bewegung Schweiz Jahresbericht 2012, L&S Sozialforschung und Beratung AG, 2012.
[38] G. Ruedl, H. Bilek, H. Ebner, K. Gabl, M. Kopp, M. Burtscher, Fatalities on Austrian ski slopes during a 5-year period, Wilderness Environ. Med. 22 (4) (2011) 326–328, https://doi.org/10.1016/j.wem.2011.06.008.
[39] F.P. Rivara, D.C. Thompson, R.S. Thompson, V. Rebolledo, Injuries involving off-road cycling, J. Fam. Pract. 44 (1997) 481–485.
[40] R.L. Kronisch, R.P. Pfeiffer, Mountain biking injuries: an update, Sports Med. 32 (8) (2002) 523–537, https://doi.org/10.2165/00007256-200232080-00004.
[41] F. Feletti, E. Brymer, Injury in kite buggying: the role of the 'out-of-buggy experience', J. Orthop. Surg. Res. 13 (1) (2018) 104, https://doi.org/10.1186/s13018-018-0818-x.