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Review article: A scoping review of human factors in avalanche decision- making

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Abstract

The interest in understanding the human aspects of avalanche risk mitigation has steadily grown over the past few decades. Between 2001–2011, 11 research papers on decision-making in avalanche terrain were published in peer-reviewed journals. Between 2012–2022, this number rose to 55. These papers have been authored by researchers from various disciplines and publications in journals across different fields. Despite the field's nascent stage, to guide future research it is pertinent to provide an overview of the insights from existing research literature.

This paper offers a systematic overview of peer-reviewed research on human factors in avalanche decision-making. The overview is based on a systematic literature search covering research published up until the end of 2022. The search was conducted across six databases, including Scopus and Web of Science, using a set of keywords related to avalanche decision-making (e.g., "decision-making," "backcountry skiing," "avalanche terrain," "avalanche accident"). Out of nearly 13,000 articles containing at least one of the key search terms, 70 had a research question related to avalanche decision-making and were published in peer-reviewed academic journals. Additionally, 100 relevant papers were published as ISSW (International Snow Science Workshop) proceedings.

We coded all identified papers based on major and minor research questions, control variables, population covered, and methodology. 12 concepts described the different research themes (e.g., avalanche accidents, avalanche education, decision-making strategies). We applied the concepts to the 70 peer-reviewed papers and present them by their main concept.

1 Introduction

1.1 Rationale

Approximately 90% of fatal snow avalanche accidents are triggered by the victim or someone in their group (Schweizer and Lütschg, 2001). This underscores that avalanches are more of a human issue than a snow issue. Over the past two decades, there has been a growing body of research focusing on human factors in avalanche terrain. The topic has been of interest for researchers across multiple disciplines, such as economy, geography, outdoor and recreation, political science, psychology, and public safety and engineering research. Human factors encompass any human influences that affect the assessment of avalanche risks and the decision-making process (Haegeli et al., 2023). However, the concept of human factors is broad and not easily defined, and different research traditions offer different approaches, thus creating a body of knowledge that is heterogeneous in nature. To create a more informative and productive foundation for future research on human factors in avalanche decision-making, we conducted a qualitative systematic scoping review.

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

1.2 Objectives

By conducting a scoping review, we wished to examine the extent, range and nature of the evidence so far produced on human factors in avalanche terrain. The following research question has guided this effort:

What literature exists on how human factors affect decision-making and/or risk assessment done by individuals who expose themselves to avalanche prone terrain?

The main objectives of our research were:

a. To design and implement a systematic literature search on the topic of human factors in avalanche terrain.
b. To identify relevant literature and extract data from the papers to make a detailed overview over this literature.

2 Methods

2.1 Scoping review

A scoping review is a type of knowledge synthesis that follows a systematic approach to map evidence on a topic and identify main concepts, theories, sources, and knowledge gaps (Tricco et al., 2018). Unlike systematic reviews, which typically address narrowly focused research questions, scoping reviews cover broader topics and are often used to identify and analyze the extent, range, and nature of research activity in a particular field. By choosing this approach, and by guidance of the PRISMA-ScR checklist, we wished to summarize findings from a body of knowledge that is heterogeneous in both methods and discipline, and to reveale uncharted research areas within the avalanche research field.

2.2 Eligibility criteria

Our guiding principle has been that human factors must be central in the included papers. We identified literature where human factors influence actual decision-making or risk assessment while exposed in avalanche terrain, but also in the preparation phase before entering avalanche terrain. Preparation may include both trip planning as well as avalanche education (Greene et al., 2023). Literature focused on decision-making tools was considered relevant in cases where use of the tool is related to human factors in decision-making, but not where the focus is on how the tool relates to weather, terrain, and snowpack aspects. In the following paragraphs we will elaborate and rationalize our criteria for inclusion and exclusion.

2.2.1 Publication status

Human factors in avalanche terrain is a nascent research field that has attracted a large interest among both practitioners, stakeholders and users of avalanche terrain. There is a substantial number of relevant papers that are not published peer-reviewed (gray literature), mainly as proceedings from the International Snow Science Workshop (ISSW), or as undergraduate and graduate theses (BA, MSc, PhD). We have only included peer-reviewed results in this paper. The reason is the large spread in quality of the non-peer-reviewed literature, making it difficult to set stringent eligibility criteria. However, we have searched through and extracted data from all

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

relevant papers, and the relevant papers with extracted data from the gray literature can be found at https://osf.io/u9ydm/

2.2.2 Participants

All people exposed to avalanche terrain in the backcountry, side country or in out-of-bounds terrain were considered eligible research participants in the included sources of evidence. This includes participants maneuvering avalanche terrain by snow mobiles, snowboard, snowshoes, and skis, and by foot. Recreationalists, professional guides, avalanche safety instructors and educators, ski area patrollers, avalanche professionals (observers, bulletin makers, investigators), as well as other personnel that are expected to personally mitigate and consider avalanche risk (e.g. field geologists, trained soldiers) were included as participants. People appearing as participants through accident reports were also included in the review, as profile information of avalanche victims is considered important information on how human factors may have played a vital role in the decision-making process prior to the avalanche accident. Travelling into avalanche terrain might be self-assisted, snowmobile assisted, lift-assisted, or motor vehicle assisted (e.g., helicopter, snowcats).

People travelling by vehicle on roads exposed to avalanche terrain were not included in this review. The rationale behind this is that decisions concerning road risk and safety are made by official authorities, and not by the individuals themselves. Residents living in avalanche exposed areas were excluded from our study by the same rationale.

2.2.3 Years considered

In order to include pioneer research and publications that has worked formatively for the development of the field we did not set a lower limit for publication year. Our search has been running up until the end of 2022.

2.2.4 Language

Our study has limited its inclusion to sources written in English.

2.2.5 Exclusion criteria

We chose to exclude research that focuses strictly on 1) avalanche rescue and medical issues, 2) technical aspects of weather, terrain, avalanche dynamics and forecasting, and 3) management of operations where the decision-maker is not personally affected by the avalanche threat (like risk management in a ski-resort). Our rationale for excluding these important fields is that these research areas do not analyze how individuals personally deal with the threat of being involved in an avalanche accident. We also excluded articles where humans and human behavior in avalanche terrain is secondary, or implied as part of the research (e.g., extensive accident reports, outdoor or adventure focus). Topics such as decision-making related to rescue after an avalanche has occurred, including medical issues, were not included in the search. Neither were natural science studies or studies primarily focusing on building or technical aspects of avalanche forecasting. However, we note that we did include studies that investigated the effect of avalanche forecast on human factors. Finally, we excluded sources of evidence where the full text was not obtainable, or where human factors were auxiliary or briefly mentioned but were not among

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

the main themes. The excluded topics are also of interest to the scientific community, but will require separate searches and are not within the scope of this review.

2.3. Information sources

We defined six databases and search engines as relevant to our topic "human factors in avalanche terrain". As the topic is not easily restricted to a specific discipline, *Web of Science* and *SCOPUS* were considered useful sources. They both offer access to multiple databases that reference cross-disciplinary research. Two other discipline specific databases, *PsycINFO* and *Hospitality & Tourism Complete,* were chosen because of the assumption that human factors in avalanche terrain would be published in these academic disciplines. Our previous knowledge of the existing literature led us to this assumption. In addition, we also ran the search in the ISSW proceedings database and ProQuest – a database covering dissertations from a range of disciplines. The results from the latter two, primarily originating from the ISSW database, have been subject to the same procedure as the peer-reviewed articles presented in this paper. The results, included the extracted data, can be found in supplementary materials (see https://osf.io/u9ydm/). *Google Scholar* was used as a tool in preliminary searches, and to supplement the final search. We conducted the search between April 27th, 2017, and December 31st, 2022. Where sources of evidence were found as references or abstracts, but with missing full texts, effort was made to retrieve these texts by requests to relevant libraries or by contacting authors.

2.4 Search

2.4.1 Identifying relevant keywords for systematic search

We identified keywords using an iterative process. In the first phase, we searched Google Scholar using intuitive search words such as ("human factor in avalanche terrain"). We thereafter used the relevant keywords in the identified papers in a second systematic search: «The Human Factor in Avalanche Terrain".

The keywords and phrases chosen for our search were selected first based on their frequency in the keywords overview (see *keyword, selection.docx* for more details). Other keywords have been added after consulting with researchers familiar with the field. We ran several preliminary searches in the named databases to refine the final set of keywords. The size of the search result has been guiding as to define the relevance and usefulness of the keywords.

2.4.2 Building the search

We created two bins, 1) human factor and 2) avalanche. These two bins have a list of associated keywords. Any paper with keywords that matched both bins would be listed as a result. The search is built using the Boolean operators OR and AND, where OR is used between all the keywords within the main categories and AND is used to combine the two categories for the final result. We searched for keywords in titles, abstracts, and listed keywords. Thesaurus terms (pre-defined keywords for specific databases) have been added to the databases with this functionality. The table below provides an overview of relevant categories of keywords in the two bins (for more details see *Identifying keywords.docx* and *Keywords, overview.docx* at https://osf.io/u9ydm/).

Table 1 Overview over keywords included in search.

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

Main category "human factor" (combined with OR):		Main category "avalanche" (combined with OR):
- Human factor and human error - Decision-making and decision support - Risk (…) - Education and training - Heuristics, cognitive bias and intuition - Situational awareness and pattern recognition - Group dynamics/management/factors - Expertise/expert/professionals and guiding	The two bins are combined with AND. Papers with a match in both categories are listed as result	- Avalanche - Backcountry, side-country, off-piste and off-bounds - Skier, snowshoer, snowmobiler, snowboarder - Adventure recreation/tourism

2.5 Selection of sources of evidence

The final search result from the individual databases and search engines were added to our library, and duplicates were filtered out. Guided by our research objectives and eligibility criteria, a preliminary screening was performed based on title and abstract, separating obviously ineligible studies from possible eligible ones. We used a folder structure categorizing sources as included, uncertain and excluded. In the next step, two researchers read the full text. Notes were subsequently compared, and in cases where there was disagreement, the papers were discussed in depth and a conclusion was drawn based on the extent of how they answered to the research objectives and fulfilled the eligibility criteria. This process was repeated in three iterations. The final result yielded 70 peer- reviewed papers. We also conducted the same process for the ISSW proceedings.

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

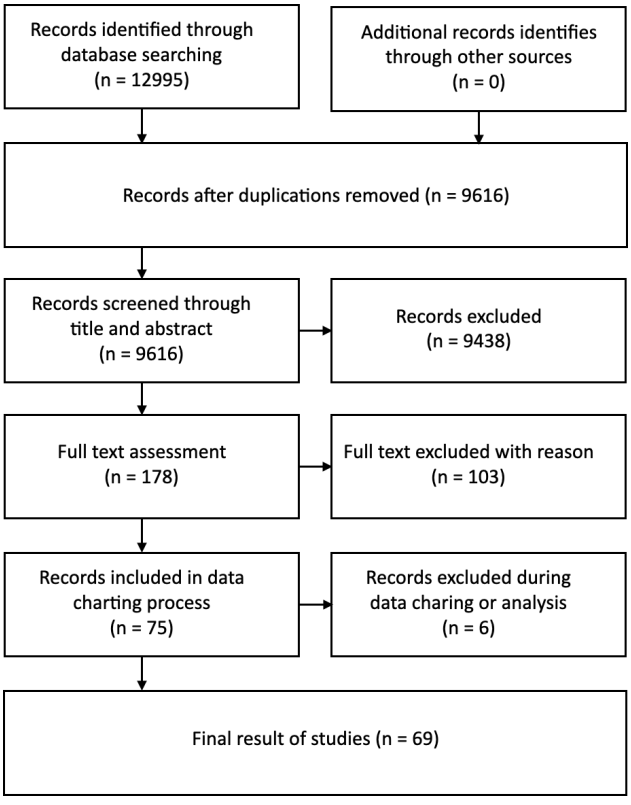

Figure 1. Flow diagram of the search

2.6 Data charting process

To extract relevant data from the papers, two of the authors developed a matrix schema for charting data from the sources of evidence included. Data was extracted on the basis of year of publication, type of publication, sampling procedure, method of data collection, type of study design, participants (e.g., self- or lift assisted recreationalists, avalanche educators, avalanche forecasters), risk target (the population at risk, e.g., recreationalists, avalanche professionals), focus of study, main explanatory factor, if existing, and, if relevant, control variables of data. Two independent researchers extracted and coded the data. Notes were subsequently compared and discussed, and if the two coders were not in agreement, or any kind of uncertainty was identifiable, a conclusion was made based on a further discussion with an extended panel of one or two researchers. Table 2 provides a description of the categories of extracted data.

Table 2 Description of the categories of extracted data from the data charting*

Risk target	Population	Sample	Method 1a	Method 2a	Method 3	Focus 1 + focus 2	Factor 1 + factor 2	Control variables
Recreationalists	Self-assisted recreationalists	Randomized	Survey	Reflection on attitude	Quantitative	DM-errors	FACETS	Socio-demographic
General public	Lift-assisted recreationalists	Convenience field	Field observation	Discrete choice experiment	Qualitative	DM-tools	Other heuristic bias	Experience
Avy professionals	Heli-assisted recreationalists	Convenience online	Accident analysis	GPS tracks	Mixed design	DM-expertise	Risk perception/attitude	Avy training
Avy victims	Motor-assisted recreationalists	Convenience other	Field/lab experiment	User frequency in field	Other	Bayesian perspective	Group dynamics	Avy knowledge
Other field workers	Participants of guided groups	Data from sources	Lit. review/overview	Online user frequency	(theoretical,	Risk perception	Other social factors	Avy experience
Other	Recreationalists not defined	No sample	Review accidents	Participatory observation	conceptual,	Group dynamics	Leadership	Other variables
Tourist industry	Backcountry guides		Interview	Field experiment	overview etc.)	Demographics	Avy experience	
	Ski area patrollers		Media as data source	Lab experiment		Avy education	Avy DM competence	
	Avy safety instructors/educators		Review of avy danger	Focus groups/ interviews etc.		Planning	Avy danger level	
	Avy professionals not defined		Theoretical model	Discourse analysis		Accidents/incidents	Avy problem	
	Avalanche victims (acc. Reports)		No data collection	Analysis of accidents		Avy victims	Risk communication	
	Professionals field workers		Critique of theory/tool	Theoretical modelling		Safety culture	DM-Aid	
	Public authorities			Comparison to risk in other fields		Recreation specialization	Goals and policy statements	
	Residents in avy exposed terrain			Calculated prevention values		Human factors	Physical activity	
	No sample (theoretical etc.)			Demographic survey		Risk communication	Planning / info seeking	
				Collection of snow/weather data		Process of DM	Human factors	
				Literature review/ overview		Safety equipment	Avy education /awareness	
				No data collection		Media/opinions on avy	Recreation specialization	
						DM related to terrain	Media/opinions of risk	
						Forecast/danger rating	Weakness in DM-process	
							Safety measures/equipment	

Avy = avalanche (e.g. avy professional – avalanche professional), DM = Decision-making

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

2.7 Categorization of papers according to their main focus

We coded all papers according to their main focus. The different focus themes were developed using an iterative process. One of the authors suggested a first set of themes, based on a previous, non-systematic, review of the literature. During the data's coding process, the two coding researchers could add themes if a paper did not fit the existing themes. In total, 20 themes were identified in the eligible material.

Organizing the literature into 20 themes provides an overview of topics covered in the literature so far. However, some of the topics identified are very narrow, and others overlap. The high number of topics may also make the overview less clear. We therefore decided to revise the codes into a smaller number of research themes. Three of this paper's authors made an initial suggestion of eight research themes. These themes were sent to three international collaborators for feedback and discussion. Based on the discussion, the themes were revised into 12 main research themes (Table 3).

Table 3. Final research themes.

Research theme	Description
Biases & decision-making errors (BE)	All biases and errors.
Risk communication (RC)	Effects of risk communication on learning, understanding, risk perception, decision-making.
Avalanche education (AE)	Effects of avalanche education on learning, and decisions. Content analysis of avalanche education.
Experience (EXP)	Experience of travelling in the backcountry and/or assessing avalanche risk. How/what people learn from experience. How experience affects decision-making.
Risk perception (RP)	Risk judgment, perceived danger/safety. Effects on and of risk perception on decision-making.
Willingness to take risk (WTR)	Measures of risk attitudes. Factors that affect willingness to take risk. Effects of willingness to take risk on decisions.
Social factors (SF) and group decision-making (GDM)	Effects of group dynamics and other social factors on individual and group decision making.
Avalanche accidents (AA)	Factors that affect the risk of being involved in avalanche accidents (incl. accident analysis). Effects of avalanche accidents on decisions, preferences, and perception.
Population characteristics (PC)	Descriptions of characteristics of certain populations or sub populations.
Decision-making strategies (DMS)	Studies of decision-making tools, strategies, processes, factors.
Motivation (M)	Studies on motives for activities and effects of motivation on decision making.
Methods and theory (MT)	Studies that mainly focus on describing/developing new methods or theory.

Two of the authors and the three international collaborators thereafter assigned independently at least one concept to each paper in the dataset. The assignment was based on the focal research question of the article, and not based on the potential relevance for a given research area. For example, studies analyzing avalanche education directly

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

were assigned the concept 'avalanche education', while studies that might be relevant for avalanche education but did not explicitly investigate the effects of avalanche education or avalanche course curricula were not assigned this concept. Since some papers cover more than one topic, we provided each paper with up to three different concepts. In cases of disagreement, notes were compared and discussed, and concepts were adjusted.

3. Result

Of the 12,995 articles that contained at least one of the keywords in the two categories, 76 fulfilled the eligibility criteria and were included in the dataset. During the analysis of the data, we discovered that six of the identified papers did not have human decision-making as their main focus. These papers were therefore removed, and the final data set contained 70 articles.

The eligible papers have publication dates ranging from 1999 to 2022. Over half (N=56) were published in the last 10 years and more than a quarter (N=22) since 2020. Most studies (N=43) rely on quantitative methods. A relatively small number uses qualitative (N=9) or mixed methods (N=11). Only three studies use randomized sampling strategies. Seventy percent rely on convenience samples (N = 50). Sixty-four percent (N = 46) of the articles study backcountry recreationalists. The result from the data charting process with extracted data can be found at https://osf.io/u9ydm/.

3.1 Main research themes in the eligible literature

We provide a brief overview of the research themes situated based on research traditions and concepts from related research fields. The list is not meant to cover all potentially relevant research themes on the human dimension of avalanche risk. In Table 5 the papers are sorted on the different research themes.

3.1.1 Biases and decision-making errors (N = 11)

A range of cognitive and motivational biases can influence decision making, including those related to risk analysis (Montibeller and Winterfeldt, 2015), human judgment (Kruglanski and Ajzen, 1983), and strategic planning (Barnes, 1984). The origins of these biases can be traced to both innate and acquired factors, as well as to environmental influences (Croskerry et al., 2013). Despite the prevalence of these biases, individuals often fail to recognize them in their own decision making (Pronin, 2007). Additionally, decision makers can fall into psychological traps such as the anchoring trap and the status quo trap (Hammond et al., 1998).

The papers in this review include a wide range of factors that potentially affect perceptions of risk or skill and/or decisions, like over-confidence (e.g. Bonini et al., 2018), heuristic traps (e.g. Furman et al., 2010), availability affect (e.g. Mannberg et al., 2021a) framing effects (e.g. Stephensen et al., 2021) but also theoretical (e.g. Zajchowski et al., 2016) and environmental factors (e.g. Wickens et al., 2015). Existing studies in this category typically investigate if people make biased judgements and/or how biases and heuristics affect decision-making in avalanche terrain.

3.1.2 Risk communication (N = 9)

Risk communication is a critical aspect of informing the public about potential risks, particularly in public health emergencies (Glik, 2007; Wachinger et al., 2013) and has an impact on risk perception and decision-making

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

(Williams and Noyes, 2007). However, it is often challenging due to the complexity of risk information and the need to consider and understand the audience beliefs, values and concerns (Keeney and von Winterfeldt, 1986; Fischhoff, 2015). The presentation of risk information can significantly impact its effectiveness, with visual aids such as graphics playing a key role (Lipkus and Hollands, 1999).

Within the avalanche context, the tag mainly concerns communication via avalanche bulletins. Existing studies in this category cover both how different groups use and understand the content in avalanche bulletins (e.g. Fisher et al., 2022) and how the presentation of the information aids or hampers understanding (e.g. Engeset et al., 2018).

3.1.3 Avalanche education (N = 4).

Education plays a crucial role in the ability to conduct risk management in uncertain environments (Carmen Nadia Ciocoiu and Daniel Neicu, 2007). Education may also help understanding risk and uncertainty (Bob Manson, 2018; Stalker, 2003). The effect of education is pivotal, especially in activities that take place in complex and wicked environments, where potentially fatal situations are a possibility.

Two of the four existing studies discuss the role of heuristic traps in avalanche courses (Johnson et al., 2020; Zajchowski et al., 2016). The third study concerns how the processing skills of avalanche bulletin information vary among recreationists, and how this can be an avenue for continuing education (Fisher et al., 2022). The fourth study evaluates the effect of avalanche education on risk perception (Greene et al., 2022). It should be mentioned that many studies use avalanche education as one of many control variables, but these studies are not included under this tag. The four papers in this category do not cover effects of avalanche education on knowledge and skills, and analyses of the structure and content of avalanche courses.

3.1.4 Experience (N = 2)

Experience can build expertise and therefore significantly impact risk management, but the role of experience in the risk identification process is much less significant than it is commonly assumed to be (Maytorena et al., 2007). Particularly, in wicked learning environments where feedback is sparce, experience does not necessarily lead to expertise (Hogarth et al., 2015).

There are only two papers in this category. One of the studies proposes a new way of measuring expertise. The other investigates how skill affects assessments and understanding of avalanche risk. However, several other papers have this as auxiliary concept, e.g., Landrø (2020) studies experts' decision-making.

3.1.5 Risk perception (N = 10)

Risk perception is a complex phenomenon influenced by various factors and covers both the perceived likelihood of an outcome, and how dangerous the outcome is perceived to be. Humans have a poor understanding of probabilities (Hertwig and Erev, 2009). Several studies highlight the role of emotions and cognitive processes in shaping risk perception (Slovic, 1987; Slovic et al., 2007). Other contributing factors are personal experiences and cultural factors (Hicks and Brown, 2013; Wachinger et al., 2013) and attitude, risk sensitivity, and specific fear (Sjöberg, 2000; Joffe, 2003).

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

In the avalanche literature, studies have focused on a variety of factors that impact risk perception like impact from experience of fatal avalanche events (e.g. Leiter, 2011), cognitive effect of framing (e.g. Stephensen et al., 2021), physical effects of activity (e.g. Raue et al., 2017) or effect of travel strategies (e.g. Michaelsen et al., 2022) or impact of online user platforms (e.g. Plank, 2016).

3.1.6 Willingness to take risk (N = 10),

While risk perception describes a person's understanding of how likely or dangerous a situation is, risk preferences, or willingness to take risk describe how much they like or dislike the situation given the perceived risk (Dohmen et al., 2011; Pratt, 1978). Willingness to take risk is tied to demographic factors like gender, age, height, and parental background (Dohmen et al., 2011), individual factors like sensation seeking (Sharifpour et al., 2013), risk conception and positive feelings (Dohmen et al., 2018; Isen and Patrick, 1983) or social factors like influence from peers and mortality salience (Hirschberger et al., 2002; Woodside, 1972) and external factors (Hetschko and Preuss, 2020; Savage, 1993).

Existing studies in this category typically study how risk preferences correlate with decisions (e.g Haegeli et al., 2012; Mannberg et al., 2018), or how willingness to take risk correlate with participant characteristics like gender and age (e.g. Mannberg et al., 2018; Walker and Latosuo, 2016) or co-hort (e.g. Haegeli et al., 2012; Kopp et al., 2016) or external factors like equipment (e.g. Haegeli et al., 2020).

3.1.7 Social factors and group decision-making (N = 6). Being in a group affects performance and decision making in multiple ways (Kerr and Tindale, 2004). A group will often outperform individual decision makers (Kugler et al., 2012). However, negative group factors have been repeatedly shown to decrease decision quality (Kroon et al., 1991) and lead to higher risk taking (Bougheas et al., 2013) and can lead to fatally flawed decisions (Sunstein and Hastie, 2008). Group size has been shown to be an important predictor, where large groups can lead to riskier decisions, and challenge communication within groups where groups may only discuss already shared information and hold back information that is only known to parts of the group (Stasser and Titus, 1985).

Studies in this category include formation, leadership and decision making in groups (e.g. Zweifel and Haegeli, 2014), social aspiration (e.g. Mannberg et al., 2021b) , moral boundaries (Tøstesen and Langseth, 2021), group size (Zweifel et al., 2016), organizational culture (Johnson et al., 2016) and decision-making within groups, and how groups affect the decisions made by individuals (Ebert and Morreau, 2023). There is a large spread in the focus of existing studies. Topics include group formation, how group size, composition, decision rules affect the quality of decisions, and how organizational and social norms affect behavior.

3.1.8 Avalanche accidents (N = 10).

Accident studies in general offer valuable insights into the causes and prevention of accidents and provide opportunities for learning (Balasubramanian and Louvar, 2002; Hovden et al., 2011). However, accidents are complex phenomena which benefit from a comprehensive approach (Cedergren and Petersen, 2011; Moura et al.,

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

2017). Yet, feedback from experience and accidents are important for improving operational security (Croft, 2020; Lindberg et al., 2010).

Studies in this category includes trend in accident rates (e.g. Berlin et al., 2019; Page et al., 1999), correlates of avalanche accidents and demographic factors (e.g. Jekich et al., 2016; Peitzsch et al., 2020), victim profile (e.g Soule et al., 2017), group size (Zweifel et al., 2016), fatality risk in helicopter and snow cat skiing (Walcher et al., 2019) and organizational culture (Johnson et al., 2016). The existing studies typically characterize avalanche victims or the situation leading up to the accident.

3.1.9 Population characteristics (N = 11).

People travelling in avalanche terrain are not one homogeneous group, but rather a heterogeneous collection of people with different motives, skills, ways and means of travel. Tailoring risk mitigation strategies to specific user groups is crucial for their effectiveness (Bartolucci et al., 2023).

This concept is broad. It includes studies that in some way characterize a "population", regardless of size. Studies in this category present characteristics for different populations in terms of safety practices (Nichols et al., 2018; Silverton et al., 2007, 2009), use of avalanche safety equipment (e.g Ng et al., 2015) and broader focus on human factor and motivation among different groups (Jackman et al., 2023; Sole et al., 2010).

3.1.10 Decision making strategies (N = 17) Decision making under uncertainty is a complex process that requires a range of strategies. These strategies can take many forms, from pre-defined (rule-based) strategies to heuristics (Gigerenzer and Gaissmaier, 2011) or vaguely defined habits (Verplanken and Aarts, 1999). And in the decision making process the decision makers need to consider a wide range of potential states and outcomes, as well as the reliability of information.(Hansson, 1996; Polasky et al., 2011). Coping with such uncertainty requires mental preparedness, agility, and the ability to react to unforeseen events (Kleindorfer, 2008).

The existing literature on decision-making strategies has a very large spread both concerning method and focus. The studies typically either describe or test relevant strategies, underlying decision-making factors, or use of decision-making aid in different user groups.

The 17 papers cover both methodological procedures (e.g. Sterchi and Haegeli, 2019; Thumlert and Haegeli, 2017), as well as empirical collected data on human behavior and mitigation strategies in avalanche terrain (Michaelsen et al., 2022). The literature span investigations of professionals (e.g Løland and Hällgren, 2023) and recreationists (e.g Grimsdottir and McClung, 2006), and covers research on decision-making strategies of backcountry skiers (e.g Pfeifer, 2009; Witting et al., 2021), mechanized based skiing (e.g Hendrikx and Johnson, 2016; Sterchi and Haegeli, 2019), as well as snowmobilers (e.g Baker, 2013; Michaelsen et al., 2022).

3.1.11 Motivation (N = 3)

Motivation potentially affects a wide range of factors that drive risk exposure (Kerr and Houge Mackenzie, 2012) and engaging in analytical thinking (Mækelæ et al., 2023). In the avalanche context, this relates to, e.g., terrain choices, educational choices, information search, use of risk-mitigation strategies etc.

The concept covers studies that either describe motivational factors in different user groups (Frühauf et al., 2019),

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

or how motivations affect decision-making. The three existing papers in this category focus mainly on motives to seek risk among lift-assisted skiers (Frühauf et al., 2019, 2020; Fruhauf et al., 2017).

3.1.12 Methods and theory (N = 7).

The field of social science is characterized by a broad but important variety of theory and methods (Porta and Keating, 2008). Example of methods can be observation studies, interviews, surveys and experiments each with their own strengths and limitations (Herzog, 1997). It is therefore important to consider the specific research problem and context when choosing what methodological tools to apply.

The existing studies includes papers that develop and describe a new theory or a new empirical method to collect or analyze data that can help gain a better understanding of human factors in avalanche terrain.

Several of the existing papers in this category present methods for GPS-tracking in combination with surveys, to collect data on terrain-use and travel behavior in recreational out-of-bounds skiing (Johnson and Hendrikx, 2021; Sykes et al., 2020). Further, this concept covers methodological investigations to document terrain preferences (Saly et al., 2020) and terrain selection practices (Thumlert and Haegeli, 2017).

In table 5 the different papers from all the 12 research themes are presented with their different theme tag.

Table 5. Eligible papers sorted on main research theme. One paper can be tagged in up to three research themes.

Author(s)	Title	Year	Tag 1	Tag 2	Tag 3
Johnson, J; Mannberg, A; Hendrikx, J; Hetland, A & Stephensen, M	Rethinking the heuristic traps paradigm in avalanche education: Past, present and future	2020	1 - Biases & DM errors	3 - Avalanche education	
Zajchowski, C. A. B., Browniee, M. T. J., & Furman, N. N.	The Dialectical Utility of Heuristic Processing in Outdoor Adventure Education	2016	1 - Biases & DM errors	3 - Avalanche education	
Bonini, N., Pighin S., Rettore, E., Savadori, L., Schena, F., Tonini, S. & Tosi, P.	Overconfident people are more exposed to "black swan" events: a case study of avalanche risk	2018	1 - Biases & DM errors	5 - Risk perception	
Stephensen, M. B. & Martiny-Huenger, T.	Liking and perceived safety across judgments of distinct instances of a category of activity	2021	1 - Biases & DM errors	5 - Risk perception	
Marengo, D., Monaci, M. G., & Micell, R.	Winter recreationists' self-reported likelihood of skiing backcountry slopes: Investigating the role of situational factors, personal experiences with avalanches and sensation-seeking	2017	1 - Biases & DM errors	6 - Willingness to take risk / risk preferences	
Furman, N., Shooter, W., & Schumann, S.	The Roles of Heuristics, Avalanche Forecast, and Risk Propensity in the Decision Making of Backcountry Skiers	2010	1 - Biases & DM errors	2 - Risk communication	6 - Willingness to take risk / risk preferences
Ebert, P. A.	Bayesian reasoning in avalanche terrain: a theoretical investigation	2019	1 - Biases & DM errors		
Mannberg, A., Hendrikx, J., Johnson, J. & Hetland, A.	Powder Fever and its Impact on Decision-Making in Avalanche Terrain	2021	1 - Biases & DM errors		
Wickens, C. D., Keller, J. W. & Shaw, C.	Human Factors in High-Altitude Mounaineering	2015	1 - Biases & DM errors		
Fisher, K., Haegeli, P. & Mair, P.	Exploring the avalanche bulletin as an avenue for continuing education by including learning interventions	2022	2 - Risk communication	3 - Avalanche education	
Terum, J.A., Mannberg, A. & Hovem, F. K.	Trend effects on perceived avalanche hazard	2022	2 - Risk communication	5 - Risk perception	
Haegeli, P., & Strong-Cvetich, L. R.	Using discrete choice experiments to examine the stepwise nature of avalanche risk management decisions-An example from mountain snowmobiling	2018	2 - Risk communication	6 - Willingness to take risk / risk preferences	1 - Biases & DM errors
Clair, A. St., Finn, H., Haegeli, P.	Where the rubber of the RISP model meets the road: Contextualizing risk information seeking and processing with an avalanche bulletin user typology	2021	2 - Risk communication		
Engeset, R. V., Pfuhl, G., Landrø, M., Mannberg, A. & Hetland, A.	Communicating public avalanche warnings - what works?	2018	2 - Risk communication		
Fisher, K., Haegeli, P. & Mair, P.	Impact of information presentation on interpretability of spatial hazard information: lessons from a study in avalanche safety	2021	2 - Risk communication		
Fisher, K., Haegeli, P. & Mair, P.	Travel and terrain advice statements in public avalanche bulletins: a quantitative analysis of who uses this information, what makes it useful and what can be improved	2022	2 - Risk communication		

Author(s)	Title	Year	Tag 1	Tag 2	Tag 3
Greene, K., Hendrikx, J. & Johnson, J.	The Impact of Avalanche Education on Risk Perception, Confidence, and Decision-Making among Backcountry Skiers	2022	3 - Avalanche education	5 - Risk perception	
Hallandvik, L., Andresen, M. S., & Aadland, E.	Decision-making in avalanche terrain-How does assessment of terrain, reading of avalanche forecast and environmental observations differ by skiers' skill level?	2017	4 - Experience	10 - Decision making strategies	
Stewart-Patterson, I.	Measuring decision expertise in commercial ski guiding in a more meaningful way	2016	4 - Experience	12 - Methods and theory	
Stephensen, M. B.; Schulze, C.; Landrø, M.; Hendrikx, J. & Hetland, A.	Should I judge safety or danger? Perceived risk depends on the question frame	2021	5 - Risk perception	1 - Biases & DM errors	
Groves, M. R. & Varley, P. J.	Critical mountaineering decisions: technology, expertise and subjective risk in adventurous leisure	2020	5 - Risk perception	6 - Willingness to take risk / risk preferences	
Plank, A.	The hidden risk in user-generated content: An investigation of ski tourers' revealed risk-taking behavior on an online outdoor sports platform	2016	5 - Risk perception	2 - Risk communication	
Mehus, G., Mehus, A. G., Germeten, S. & Henriksen, N.	Young people and snowmobiling in northern Norway; accidents, injury prevention and safety strategies	2016	5 - Risk perception		
Raue, M., Streicher, B., Lermer, E., & Frey, D.	Being active when judging risks: bodily states interfere with accurate risk analysis	2017	5 - Risk perception		
Leiter, A. M.	The sense of snow - Individuals' perception of fatal avalanche events	2011	5 - Risk perception		
Kopp, M., Wolf, M., Ruedl, G. & Burtscher, M.	Differences in Sensation Seeking Between Alpine Skiers, Snowboarders and Ski Tourers	2016	6 - Willingness to take risk / risk preferences	9 - Population characteristics	
Walker, E., & Latosuo, E.	Gendered decision-making practices in Alaska's dynamic mountain environments? A study of professional mountain guides	2016	6 - Willingness to take risk / risk preferences	9 - Population characteristics	
Haegeli P., Gunn M., & Haider W.	Identifying a High-Risk Cohort in a Complex and Dynamic Risk Environment: Out-of-bounds Skiing-An Example from Avalanche Safety	2012	6 - Willingness to take risk / risk preferences	12 - Methods and theory	
Haegeli, P., Rupf, R. & Karlen, B.	Do avalanche airbags lead to riskier choices among backcountry and out-of-bounds skiers?	2020	6 - Willingness to take risk / risk preferences		
Mannberg, A., Hendrikx, J., Landrø, M., & Ahrland Stefan, M.	Who's at risk in the backcountry? Effects of individual characteristics on hypothetical terrain choices	2018	6 - Willingness to take risk / risk preferences		

Author(s)	Title	Year	Tag 1	Tag 2	Tag 3
Johnson, J., Haegeli, P., Hendrikx, J., & Savage, S.	Accident causes and organizational culture among avalanche professionals	2015	7 - Social factors and group DM	8 - Avalanche accidents	
Zweifel, B., Procter, E., Techel, F., Strapazzon, G., & Boutellier, R.	Risk of Avalanche Involvement in Winter Backcountry Recreation: The Advantage of Small Groups	2016	7 - Social factors and group DM	8 - Avalanche accidents	
Mannberg, A., Hendrikx, J. & Johnson, J.	Risky positioning – social aspirations and risk-taking behaviour in avalanche terrain	2020	7 - Social factors and group DM		
Ebert, P. A. & Morreau, M	Safety in numbers: how social choice theory can inform avalanche risk management	2022	7 - Social factors and group DM		
Tøstesen, G & Langseth, T	Freeride skiing - Risk-taking, Recognition, and Moral Boundaries	2021	7 - Social factors and group DM		
Zweifel, B., & Haegeli, P.	A qualitative analysis of group formation, leadership and decision making in recreation groups traveling in avalanche terrain	2014	7 - Social factors and group DM		
Berlin, C., Techel, F., Moor, B. K., Zwahlen, M., Hasler, R. M. & Swiss Natl Cohort Study, Grp	Snow avalanche deaths in Switzerland from 1995 to 2014-Results of a nation-wide linkage study	2019	8 - Avalanche accidents	9 - Population characteristics	
Soule, B., Reynier, V., Lefevre, B., & Boutroy, E	Who is at risk in the French mountains? Profiles of the accident victims in outdoor sports and mountain recreation	2017	8 - Avalanche accidents	9 - Population characteristics	
Techel, F., Zweifel, B., & Winkier, K.	Analysis of avalanche risk factors in backcountry terrain based on usage frequency and accident data in Switzerland	2015	8 - Avalanche accidents		
Jekich, B. M., Drake, B. D., Nacht, J. Y., Nichols, A., Ginde, A. A. & Davis, C. B.	Avalanche Fatalities in the United States: A Change in Demographics	2016	8 - Avalanche accidents		
Page, C. E., Atkins, D., Shockley, L.W. & Yaron, M.	Avalanche deaths in the United States: a 45-year analysis	1999	8 - Avalanche accidents		
Peitzsch, E.; Boilen, S.; Logan, S.; Birkeland, K. & Greene, E.	Research note: How old are the people who die in avalanches? A look into the ages of avalanche victims in the United States (1950–2018)	2020	8 - Avalanche accidents		
Walcher, M.; Haegeli, P. & Fuchs, S.	Risk of death and major injury from natural hazards in Helicopter and Snowcat skiing in Canada	2019	8 - Avalanche accidents		
Nichols, T. B., Hawley, A. C., Smith, W. R., Wheeler III, A. R., & McIntosh, S. E.	Avalanche Safety Practices Among Backcountry Skiers and Snowboarders in Jackson Hole in 2016	2018	9 - Population characteristics	10 - Decision making strategies	
Ng, P., Smith, W. R., Wheeler, A., & MacIntosh, S. E.	Advanced Avalanche Safety Equipment of Backcountry Users: Current Trends and Perceptions	2015	9 - Population characteristics		
Sole, A. E., Emery, C. A., Hagel, B. E., & Morrongiello, B. A.	Risk Taking in Avalanche Terrain: A Study of the Human Factor Contribution	2010	9 - Population characteristics		
Jackman, P. C., Hawkins, R. M., Burke, S. M., Swann, C. & Crust, L.	The psychology of mountaineering: a systematic review	2020	9 - Population characteristics		
Silverton, N. A., MacIntosh, S. E., & Kim, H. S.	Avalanche safety practices in Utah	2007	9 - Population characteristics		

Silverton, N. A., McIntosh, S. E., & Kim, H. S.	Risk Assessment in Winter Backcountry Travel	2009	9 - Population characteristics		

Author(s)	Title	Year	Tag 1	Tag 2	Tag 3
Grimsdottir, H., & McClung, D.	Avalanche risk during backcountry skiing - An analysis of risk factors	2006	10 - Decision making strategies	8 - Avalanche accidents	
Michaelsen, B., Stewart-Patterson, I., Rolland, C. G., Hetland, A. & Engeset, R. V.	Behaviour in Avalanche Terrain: An Exploratory Study of Illegal Snowmobiling in Norway	2022	10 - Decision making strategies	9 - Population characteristics	
Sterchi, R. & Haegeli, P.	A method of deriving operation-specific ski run classes for avalanche risk management decisions in mechanized skiing	2019	10 - Decision making strategies	12 - Methods and theory	
Thumlert, S. & Haegeli, P.	Describing the severity of avalanche terrain numerically using the observed terrain selection practices of professional guides	2017	10 - Decision making strategies	12 - Methods and theory	
Baker, J., & McGee, T. K.	Backcountry Snowmobilers' Avalanche-Related Information-Seeking and Preparedness Behaviors	2016	10 - Decision making strategies		
Hendrikx, J., Johnson, J., & Shelly, C.	Using GPS tracking to explore terrain preferences of heli-ski guides	2016	10 - Decision making strategies		
Landro, M.; Hetland, A.; Engeset, R. V. & Pfuhl G.	Avalanche decision-making frameworks: Factors and methods used by experts	2020	10 - Decision making strategies		
Løland, S. & Hällgren, M.	'Where to ski?': an ethnography of how guides make sense while planning	2022	10 - Decision making strategies		
Sterchi, R., Haegeli, P. & Mair, P.	Exploring the relationship between avalanche hazard and run list terrain choices at a helicopter skiing operation	2019	10 - Decision making strategies		
Witting, M., Filimon, S. & Kevork, S.	Carry along or not? Decision-making on carrying standard avalanche safety gear among ski tourers in a German touring region	2021	10 - Decision making strategies		
Haegeli, P, Haider, W, Longland, M, & Beardmore	Amateur decision-making in avalanche terrain with and without a decision aid: a stated choice survey	2010	10 - Decision making strategies		
Landro, M., Pfuhl, G., Engeset, R., Jackson, M. & Hetland, A.	Avalanche decision-making frameworks: Classification and description of underlying factors	2020	10 - Decision making strategies		
McCammon, I., & Haegeli, P.	An evaluation of rule-based decision tools for travel in avalanche terrain	2007	10 - Decision making strategies		
Pfleifer, C.	On probabilities of avalanches triggered by alpine skiers. An empirically driven decision strategy for backcountry skiers based on these probabilities	2009	10 - Decision making strategies		

469

Author(s)	Title	Year	Tag 1	Tag 2	Tag 3
Fruhauf, A., Anewanter, P., Hagenauer, J., Marterer, N. & Kopp, M.	Freeriding-Only a need for thrill? Comparing different motives and behavioural aspects between slope skiers and freeride skiers	2019	11 - Motivation	6 - Willingness to take risk / risk preferences	
Fruhauf, A., Hardy, W., Pfoestl, D., Hoellen, F. G. & Kopp, M.	A qualitative approach on motives and aspects of risk in freeriding	2017	11 - Motivation		
Fruhauf, A., Zenzmaier, J. & Kopp, M.	Does Age Matter? A Qualitative Comparison of Motives and Aspects of Risk in Adolescent and Adult Freeriders	2020	11 - Motivation		
Sykes, J.; Hendrikx, J.; Johnson, J. & Birkeland, K. W.	Combining GPS tracking and survey data to better understand travel behavior of out-of-bounds skiers	2020	12 - Methods and theory	10 - Decision making strategies	
Johnson, J & Hendrikx, J.	Using Citizen Science to Document Terrain Use and Decision-Making of Backcountry Users	2021	12 - Methods and theory		
Saly, D.; Hendrikx, J.; Birkeland, K. W.; Challender, S. & Johnson, J.	Using time lapse photography to document terrain preferences of backcountry skiers	2020	12 - Methods and theory		

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https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

4. Discussion

Our review shows that the number of peer-reviewed papers on the human factors in avalanche decision-making has increased substantially during the past decade. The vast majority of published studies use convenience sample methods to collect, and quantitative methods to analyze data from their participants, which mainly consists of recreational backcountry users (especially skiers).

Our review of research themes suggests that most papers have research questions related to 'biases and decision-making errors' (concept 1), 'risk communication' (concept 2), 'risk perception' (concept 5) or 'willingness to take risk' (concept 6). Many papers also fall under the categories 'population characteristics' (concept 9) or 'decision-making strategies' (concept 10). However, we would like to highlight that these two research themes are less informative than the other themes. Many of the papers in these categories provide descriptions of the behaviors or characteristics of specific groups of backcountry users. These papers were often categorized as concept 9 (population characteristics) or 10 (decision-making strategies), even if these concepts are broad.

We note that the literature on avalanche education, social factors, and experience is very limited. Avalanche education provided by trained instructors ideally leads to improved skills in risk assessment and mitigation. However, we have not found any papers analyzing the quality of avalanche education, or how courses can be improved to increase learning. Social factors are important because most decisions are made by groups, not individuals. The sociality of humans further means that our decisions are very susceptible to the influence of people around us. However, many of these factors are situational and therefore difficult to capture, even in situ. Motivation affects a wide range of behaviors, including information seeking and use of products and services, terrain choices and risk assessments. Finally, due to the inherent lack of feedback, experience and expertise are not as closely linked in avalanche context as in other domains. Experience can therefore both improve and deteriorate decisions.

4.1 Limitations

The spreadsheet containing the data from eligible papers has some limitations that should be kept in mind when used. First, to systematically assign a main concept to a paper, we focused on the paper's primary objective and focal research question. However, human factors in avalanche decision-making are a complex concept, and a single paper can encompass insights relevant to a multitude of topics. In addition, while all included studies are published peer-reviewed, the clarity of the research question, and the link between the research question and analysis, vary substantially in the final dataset. The resulting concepts may therefore provide an overly simplistic picture of the content in the current literature. Much of the literature offers insights that extend to topics beyond their main concept, and the resulting categorization should not be considered a measure of topic inclusion.

Second, while the data extraction and organization of the material followed a structured procedure, the evaluation was done by a limited number of researchers. This means that the papers have been interpreted through the lens of a few individuals. The evaluation is therefore subjective, and other researchers may have categorized the data differently.

Finally, the methodological decisions relating to the eligibility criteria, publication status, years and languages considered, and information sources for the literature were aimed to create a more systematic review. While these decisions improved the relevance, consistency, and quality of the studies, they have drawbacks in that they inherently create a publication bias. As a result, the current study is biased towards Western academic

https://doi.org/10.5194/egusphere-2024-1628
Preprint. Discussion started: 26 August 2024

perspectives in predominantly European and North American industry contexts. However, given that this study is a first attempt to consolidate this body of research from across the widely dispersed and inconsistent publishing outlets utilized by the avalanche community, it serves as a fundamental first step toward building subsequently more comprehensive and inclusive overviews of the literature.

5. Conclusion

The aim of the systematic literature search was to provide an overview of the existing body of research on human factors in avalanche decision-making. We hope the shared spreadsheet and the organization of the literature into different research themes will help researchers find relevant literature and identify important knowledge gaps that remain to be filled.

We would like to end with a call for action. The work with this literature search has been challenging for mainly two reasons. First, many papers lack clear and relevant keywords. This made it difficult to identify them in our search. Second, some of the papers proved difficult to access, even after trying to contact authors or libraries. We would therefore envision a shared database similar to PsycInfo with categorization of studies in various categories and we encourage authors to publish their papers open access so that important messages are not locked in behind pay walls. This is particularly important given that the readership may be practitioners without access to scientific libraries. Finally, we encourage researchers within the field to draw attention to existing gaps that should be closed, where assessing the quality of avalanche education is most compelling.

6. Author contribution

AH lead the project and has been involved in all stages of the project including design, implementation, and writing and editing paper. RAH: designed and ran the search, developed the sorting procedure, writing and editing, TVS: Finalizing sorting and writing and editing, AM: advice of design and implementation, writing and editing.

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8. Conflict of interest

The authors declare they have no conflict of interest.

https://doi.org/10.5194/egusphere-2024-1628
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