A SYSTEMATIC OVERVIEW OF PEER-REVIEWED RESEARCH ON THE HUMAN FACTORS IN AVALANCHE DECISION-MAKING

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ABSTRACT: Interest in the human aspects of avalanche risk mitigation has increased steadily over the past few decades. Following McCammon's (2002) seminal work on mental shortcuts that hamper decision quality in avalanche terrain (FACETS), the number of research papers on human factors has increased substantially: While only 11 research papers on decision-making in avalanche terrain were printed in peer-reviewed journals between 2001 and 2011, 55 papers were published between 2012 and 2022. These papers have been authored by researchers from a wide range of disciplines, and the papers have therefore appeared in journals in many different fields. As a consequence, it is difficult to get an overview of what we can learn from the existing research literature.

This paper aims to provide a first systematic overview of peer-reviewed research on human factors in avalanche decision-making. The overview builds on a systematic literature search, which spans research published up until the end of 2022. The search was carried out searching five databases including Scopus and Web of Science. We used a set of search words related to avalanche decision-making (e.g., "decision-making", "backcountry skiing", "avalanche terrain", "avalanche accident"). In total 12,000 articles, which contained at least one of the key search words, were evaluated. Of these, 69 had a research question related to avalanche decision-making and were published in peer-reviewed academic journals. An additional 100 relevant papers were published as ISSW proceedings. We coded all identified papers (both peer-reviewed papers and ISSW proceedings) based on major and minor research questions covered, control variables, population covered, and methodology. Finally, we developed 12 tags that describe different research themes (e.g., avalanche accidents, avalanche education, decision making strategies) and tagged the 69 peer reviewed papers.

KEYWORDS: Human factor, systematic search, avalanche research, decision-making

1. INTRODUCTION

In about 90% of all fatal avalanche accidents, the avalanche was triggered by the victim or someone in their group (McClung and Schaerer, 2006; Schweizer and Techel, 2017). This makes avalanches a human, not a snow problem. In the past 20 years, an increasing amount of research has been conducted on human factors in avalanche terrain. The topic has been of interest for researchers across multiple disciplines, such as psychology, economics, geography, public safety and engineering, political science, and outdoor and recreation research. The concept of human factors is broad and not easily definable, and different research traditions offer different approaches, thus creating a body of knowledge that is heterogeneous in nature. In a broad sense, human factors describe any human influence on the avalanche risk assessment and decision-making process.(Haegeli, P. et al., 2023)

To create a more informative and productive foundation for future research on human factors in avalanche decision-making, we present an overview of the results from a systematic scoping review. This contributes as a general overview of existing research, including theories and methodological frameworks. This paper aims to help clarify key terminology and create a more comprehensive foundation for further research.

2. METHOD

A systematic literature search is a type of knowledge synthesis that follows a systematic approach, in our case guided by the PRISMA ScR protocol (Tricco et al., 2018). This allows us to examine the extent, range and nature of the evidence so far produced on the topic of human factors in avalanche decision-making. A systematic literature search follows a pre-defined procedure: 1) defining criteria for inclusion and exclusion of papers, 2) selecting databases used to search for eligible papers, 3) identifying keywords used in

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the search, 4) defining and using a structured process to identify eligible papers, and 5) extract data from the final list of papers.

2.1 Eligibility criteria

We used 3 main eligibility criteria for including an article in our search: 1) publication status, 2) focus, and 3) research participants.

Publication status – A substantial part of the existing avalanche safety literature is constituted by so-called "grey literature", which represent studies that have been written up but not published in peer-reviewed scientific journals. This includes conference proceedings from the International Snow Science Workshop (ISSW). While the ISSW proceedings literature contains a large number of interesting studies that explore worthwhile research questions, there is a very large spread in quality, and it is difficult to create stringent eligibility criteria. The same argument applies to PhD and MSc theses that have not been published peer-reviewed. For these reasons, we did not include gray literature in our main search. However, while not presented here, we also searched and extracted references from the ISSW database. For these papers, we only included them in if they 1) contained a clear research question or objective, 2) presented a description of the method used to answer the research question or reach the objective, and 3) built on previous research (i.e., included at least one reference to peer-reviewed research). The results of the ISSW search can be found here: www.osf.io/u9ydm/

Focus - Our main search also only included research where human factors in avalanche decision-making were the *main* focus. This excluded articles where humans in avalanches was secondary, or implied as part of the research. More specifically, we chose to exclude research that focused 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 (e.g., a road authority making a decision to close a road). Our motivation for excluding these important topics was that none of these research areas analyze how humans assess or mitigate avalanche risk that affects them personally. We acknowledge that the excluded topics may be relevant for some types of research on human factors in avalanche terrain. We therefore encourage a separate scoping review of these topics.

Research participants - We excluded papers that studied people exposed to avalanche risk while travelling in vehicles on roads and residents living in avalanche exposed areas. The rationale behind this is that decisions concerning avalanche risk in these cases are made by official authorities, and not by the individuals themselves. Apart from these exclusions, we did not exclude studies based on the type of research participants. We considered all people who make decisions related to avalanche risk in the backcountry as eligible sources of evidence. This includes participants maneuvering avalanche terrain by snow mobiles, snowboard, snowshoes, and skis, as well as by foot, for recreation or as professionals. It also includes avalanche forecasters and educators. 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 affected the decision-making process prior to the avalanche accident.

2.2 Information sources

We identified five relevant databases and search engines for our literature search on 'human factors in avalanche decision-making'. Since the topic is not restricted to a specific discipline, *Web of Science* and *SCOPUS* were considered useful sources. These two platforms offer access to multiple databases that reference cross-disciplinary research. We further included two discipline specific databases: *PsycINFO* and *Hospitality & Tourism Complete*. The rational for including these databases is that many psychologists study ´human factors´ and that many recreationists, who venture into avalanche terrain, do this as tourists. We used *Google Scholar* as a tool in preliminary searches, and to supplement the final search.

2.3 Key search terms

We identified keywords using an iterative process. First, we searched Google Scholar using intuitive search words such as *human factors, decision making* and *avalanche*, and identified papers where a combination of these words occurred in the title, abstract or introduction. After that, we used the relevant keywords in the identified papers in a second search to create a list for the final search. The keywords used in the search are presented in Table 1. A full overview of the process of developing and selecting keywords and search strategies can be found in www.osf.io/u9ydm/.

Table 1. Overview over keywords included in search

Main category "human factor" (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

Main category "avalanche" (combined with OR):
- Avalanche - Backcountry, sidecountry, off-piste and off-bounds - Skier, snowshoer, snowmobiler, snowboarder - Adventure recreation/tourism

Keywords from two main categories combined with AND give the final search result.

2.4 Identifying eligible literature

We carried out the search between April 27th 2017 and December 31th 2022. In situations where sources of evidence were found as references/abstracts but full texts were missing, effort was made to retrieve these texts.

We added the final search result from the individual databases and search engines to our library and filtered out duplicates. Thereafter, we performed a preliminary screening based on the title and abstract, separating obviously ineligible studies from possible eligible ones. The sources were sorted into a folder structure divided categorizing sources as included, uncertain and excluded. In the next step, two independent researchers read and evaluated the full manuscripts of the remaining possible eligible sources. 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 to which the paper fulfilled the eligibility criteria.

3. RESULTS OF THE SYSTEMATIC SEARCH

Of the roughly 12,000 articles that contained at least one of the keywords in the two categories, 75 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 a main focus. These papers were therefore removed. The final dataset thus contains 69 articles. The papers were coded according to publication year, publication type, sampling procedure, method of data collection, type of study design (quantitative, qualitative, experimental), research participants (e.g., self- or lift assisted recreationalists, avalanche educators, avalanche forecasters), risk target (the population at risk, e.g., recreationalists, avalanche professionals), main explanatory factor, and, if relevant, control variables. Two independent researchers extracted and coded the data, and the characteristics of the papers were entered in a spreadsheet. In cases where the two were not in agreement, a conclusion was made based on a further discussion with an extended panel of additional researchers. Results with extracted data from the data charting process can be found at www.osf.io/u9ydm/.

The eligible papers have publication dates ranging from 1999 to 2022. Over half (N=55) were published in the last 10 years and more than a quarter (N=22) since the start of the past decade (2020à). Most studies (N=42) rely on quantitative methods. A relatively small number use qualitative (N=9) or mixed methods (N=11). Only three studies use randomized sampling strategies. Seventy percent rely on convenience samples (N = 49). Sixty-four percent (N = 45) study backcountry recreationalists.

We also coded each paper according to the general focus of the paper. Since some papers covered more than one topic, we included a second general focus where relevant. The different focus themes were developed using an iterative process. One researcher suggested a first set of themes, based on a previous, non-systematic, review of the literature. During the coding process of the data, the two coding researchers were allowed to 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 other 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 the authors of this paper made an initial suggestion of eight research themes. These themes were sent to the remaining authors for feedback and discussion. Based on the discussion, the themes were revised into 12 main research themes (Table 3).

Five of the authors thereafter tagged each paper in the dataset independently. The tagging was based on the research question and focus of the study, and not based on the potential relevance for a given research area. This means that e.g., studies analyzing avalanche education directly were tagged with '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 given this tag. Since some papers cover more than one topic, we provided each paper with up to three different tags. In cases of disagreement, notes were compared and discussed, and tags adjusted.

3.1 Main research themes in the eligible literature

We provide a brief overview of the research themes, and typical papers tagged with this theme. Note that the research themes discussed cover topics in the existing literature. The list is not meant to cover all potentially relevant re-

search themes on the human dimension of avalanche risk. You can find a list of the papers sorted on the different research themes in the a

Table 3. List of revised main research themes (tags)

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

Biases and decision-making errors (N = 11) include a wide range of factors that potentially affect perceptions (of risk or skill) and/or decisions (Kahneman, 2003) like over-confidence, availability, framing affect. Existing studies in this category typically investigate if people make biased judgements and/or how biases and heuristics affect decision-making in avalanche terrain.

Risk communication (N = 9) is central to the effort of informing people about risk (Wachinger et al., 2013). 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, and how the presentation of the information aids or hampers understanding.

Avalanche education (N = 3). This tag covers both effects of avalanche education on knowledge and skills, and analyses of the structure and content of avalanche courses. Two of the three existing studies discuss the role of heuristic traps in avalanche courses. The third study evaluates the effect of avalanche education on risk perception. It should be mentioned that many studies use avalanche education as one of many control variables. These studies are not included under this tag.

Experience (N = 2) can provide expertise and thereby improve decision-making. However, in wicked learning environments, experience does not necessarily lead to expertise (Hogarth et al., 2015). This tag cover topics such as requirements and obstacles for developing expertise in the backcountry. One of the two existing studies in this category propose a new way of measuring expertise. The other investigates how skill affects assessments and understanding of avalanche risk.

Risk perception (N = 10) covers both the perceived likelihood of an outcome, and how dangerous the outcome is perceived to be. There is ample evidence that humans have a poor understanding of probabilities (Hertwig and Erev, 2009). This tag includes both how internal (e.g., gender) and external (e.g., situation) factors affect perceived risk, and how risk perception affects choices. The existing literature on this topic is relatively broad, covering both perceived risk in different user groups, and the effect of situational factors on risk perception.

Willingness to take risk (N = 10), or risk preferences affect the perceived value (and costs) of different choice alternatives. While risk perception describes a person's understanding of how likely or dangerous a situation is, risk preferences describe how much they like or dislike the situation given perceived risk (Pratt, 1978)(Dohmen et al., 2011). Existing studies in this category typically study how risk preferences correlate with decisions, or how other types of participant characteristics (e.g., gender) or factors (e.g., equipment) correlate with willingness to take risk.

Social factors and group decision-making (N = 6). Being in a group affect performance and decision making in multiple ways (Kerr and Tindale, 2004). This tag includes both decision-making within groups, and how groups affect the decisions made by individuals. 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.

Avalanche accidents (N = 10). This tag includes correlates of avalanche accidents and consequences of avalanche accidents on the victim or other parties. The existing studies falling under this tag typically characterize avalanche victims or the situation leading up to the accident.

Population characteristics (N = 11). Differences in characteristics between different user groups can have important implications for the effectiveness of various products and services. The content of the tag is broad. It includes studies that in some way characterize a "population", regardless of size. Studies in this category typically present characteristics of one or more groups, e.g., skill level, experience, personality traits, motivation etc.

Decision making strategies (N = 17) can both improve and deteriorate the quality of decisions**.** These strategies can take many forms, from predefined (rule-based) strategies to heuristics (Gigerenzer and Gaissmaier, 2011) or vaguely defined habits (Verplanken and Aarts, 1999). 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.

Motivation (N = 3) potentially affects a wide range of factors that drive risk exposure (Kerr and Mackenzie, 2012). In the avalanche context, this relates to, e.g., terrain choices, educational choices, information search, use of risk-mitigation strategies etc. The tag covers studies that either describe motivational factors in different user groups, or how motivations affect decision-making. The three existing papers in this category focus mainly on motives to seek risk among lift-assisted skiers.

Methods and theory (N = 7). This category 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.

4. DISCUSSION

Our study 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, 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' (tag 1), 'risk communication' (tag 2), 'risk perception' (tag 5) or 'willingness to take risk' (tag 6). Many papers also fall under the categories 'population characteristics' (tag 9) or 'decision-making strategies' (tag 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 research theme 9 (population characteristics) or 10 (decision-making strategies, even if these tags did not fit well.

We note that the literature on avalanche education, social factors, and experience is limited so far. 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 is not as closely linked in avalanche context as in other domains. Experience can therefore both improve and deteriorate decisions.

5. 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 theme to a paper, we focused on the paper's primary objective and central research question. However, human factors in avalanche decision-making is 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 tags 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 tag, 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 to some extent 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 relevancy, 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 perspectives in predominantly modern 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 our community, it serves as a fundamental first step toward building subsequently more comprehensive and inclusive overviews of the literature.

6. CONCLUSIONS

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 that the shared spreadsheet, and the organization of the literature into different research themes will help researchers both finding relevant literature and identifying important knowledge gaps that remains 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 like to urge authors to **tag their papers with relevant keywords** (for example the research tags suggested in this paper, if relevant) and to **make sure that their work is easily available to the community**.

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