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Carry along or not? Decision-making on carrying standard avalanche safety gear among ski tourers in a German touring region

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ABSTRACT

Ski touring is a winter sport activity that enjoys increasing popularity. Recreationists practice it exclusively without using ski lifts in the backcountry, where conditions continuously and rapidly change, and avalanche danger exists. Ski tourers can increase their own and others' avalanche survival chances, among others, by carrying standard avalanche safety equipment (i.e., transceiver, probe, and shovel). Recent studies among backcountry recreationists identify various aspects to influence the decision to 'carry or not' this equipment by testing each factor individually for its statistical significance for the decision. This explorative study, in contrast, applies a new methodological approach and considers 'carry or not' as a decision process. The analysis bases on the behavioral decision theory and uses the machine learning algorithm decision tree to illustrate the decision process and examine the relative importance of each influencing feature. Therefore, we conduct a researcher-administered survey (n = 359) among ski tourers in a German touring region. According to their carrying behavior, this study classifies ski tourers into three different types: weather-oriented, complex, and conformist. Conformists always carry the avalanche equipment and are known in research. Weather-oriented ski tourers, who predominantly base their decision on environmental conditions (i.e., avalanche danger level and weather), are as new as the complex type, which relies on various features. In contrast to previous findings, personal traits play a subordinate role in the decision process of any type. Furthermore, we interpret environmental aspects in decision-making as decision heuristics that awareness-raising measures and education programs need to address.

1. Introduction

(Alpine) ski touring, a subdiscipline of ski mountaineering, is a winter sport activity, traditionally taking place in the mountainous backcountry in undeveloped natural spaces (Reynier et al., 2014). Instead of ski lifts, ski tourers use a particular boot-fixing system to walk up a mountain before skiing down an unprepared slope (Niedermeier et al., 2019). The sport has become increasingly popular in recent years (Jażdżewska, 2016; Plank, 2016): For Austria, i.e., Binder (2019) estimates that active athletes in ski touring doubled between 2009 and 2019. However, as a form of freeriding, ski touring is frequently classified as a high-risk sport by researchers (Frühauf et al., 2017) as avalanches pose a considerable risk for the athletes (Plank, 2016; Rainer et al., 2008; Volken et al., 2007). Therefore, in ski touring (unlike other mountain sports such as alpine skiing and snowboarding, cross-country skiing, or sledding), the predominant cause of death is not traumatic or cardiac events, but avalanche burials. Furthermore, ski touring has the highest mortality risk among the mountain sports mentioned (Niedermeier et al., 2020; Soule et al., 2017).

McClung and Schaerer (2006) state that most backcountry victims trigger the avalanches themselves and that these accidents result from a failure in human perception (McClung, 2002). Therefore, ski tourers can and should reduce their risk of involvement in an avalanche through avalanche prevention practices (e.g., information about avalanche danger level, avalanche education, proper risk management; see Furman et al., 2010; Haegeli et al., 2010; Procter et al., 2014; Schwiersch, 2019). Still, in the event of avalanche burial of oneself or others, carrying standard avalanche safety equipment (consisting of avalanche transceiver/beacon, shovel, and probe) is essential for rapid location and rescue (e.g., Brugger et al., 2007; Hohlrieder et al., 2005; Tremper, 2018). Despite the scientifically proven importance for the survival of oneself and others (McIntosh et al., 2007; Ng et al., 2015), recent studies demonstrate that backcountry travelers do not always carry the standard safety equipment (see Table 1 in Chapter 2) due to various reasons (e.g.,

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Eyland, 2016; Nichols et al., 2018; Silverton et al., 2007).

Researchers explore the factors influencing the decision to carry safety equipment for some time: Nichols et al. (2018) and Procter et al. (2016), e.g., identify the relevance of sociodemographic aspects as well as ski touring expertise, Marengo et al. (2016) the influence of direct and indirect avalanche experience, Groves and Varley (2020) the critical attitude regarding technical aids and self-confidence, Ng et al. (2015), Procter et al. (2014), and Silverton et al. (2007), e.g., the importance of avalanche education. However, the studies conducted so far have in common that they examine each potential influencing factor individually for its statistical significance on carrying standard avalanche safety equipment among backcountry recreationists. Moreover, these studies do not consider environmental factors. Only Nichols et al. (2018) include avalanche hazard forecasts into their analysis and, since that forecast depends (among other things) on the weather, therefore indirectly consider environmental factors.

In contrast to previous research, we assume that ski tourers have access to the standard avalanche safety gear and we consider carrying standard equipment as a decision process and embed our study within the behavioral decision theory. The objectives of the study are as follows:

1) To evaluate the relative importance of various factors for the decision to carry the standard avalanche safety equipment. In the process, we add further factors to those previously known from research, including those suggested to us in expert interviews.
2) To unfold and illustrate the decision-making process ‘to carry along or not’ the standard safety equipment and the dependence of these influencing factors on each other, and
3) to offer a classification of ski tourers concerning their carrying behavior of standard safety equipment for research and practice.

For this purpose, we conduct a survey among 359 ski tourers in the ski touring region Taubenstein (Germany), which we analyze using the machine learning algorithm decision tree. The results might provide public and private entities involved in ski touring a better understanding of the decision process for carrying avalanche safety equipment. The classification also shows whom awareness-raising measures should address to achieve the greatest possible effect.

The remaining part of this paper is structured as follows: Chapter 2 provides a profound overview of the influencing factors on carrying standard safety equipment among ski tourers in recent studies. Chapter 3 presents the data and the method used in this study. The results are then presented in chapter 4 and discussed regarding their meaning and relevance in chapter 5. The paper concludes with a summary of the main findings, the study’s limitations, and an outlook for further necessary research in chapter 6.

2. Background of the study

Several studies emphasize the importance of avalanche safety gear and its proper use to increase the chance to survive an avalanche event (e.g., Brugger et al., 2007; Haegeli et al., 2014). The first 15 min after burial are decisive, which is why uninjured companions play a central role in extrication (e.g., Falk et al., 1994; Procter et al., 2016). To ensure quick recovery, backcountry recreationists need to carry standard avalanche safety equipment on every tour. Furthermore, they need to gain and maintain knowledge and skills on basic techniques of search and rescue through education and training (van Tilburg et al., 2017). The use of a transceiver, for example, reduces the duration of burial and mortality among avalanche victims in the backcountry substantially (Brugger et al., 2007; Hohlrieder et al., 2005). Nevertheless, the mortality rate among fully buried victims is still high (around 50%) (Brugger et al., 2001; Hohlrieder et al., 2005; Procter et al., 2016), primarily due to asphyxiation (Boyd et al., 2009; Haegeli et al., 2011; Hohlrieder et al., 2007; McIntosh et al., 2007). Carrying an avalanche airbag can prevent complete burial, which reduces the mortality rate significantly (Brugger et al., 2007; Haegeli et al., 2014). Completely buried avalanche victims, in turn, can extend their survival time within the avalanche and avoid asphyxia through self-created air pockets (Brugger et al., 2007; Falk et al., 1994; Procter et al., 2016) or breathing devices, such as AvaLung™, that create artificial air pockets (Grissom et al., 2000). However, the use of additional avalanche devices may lead to an increased risk-taking propensity among backcountry recreationists (Eyland, 2016; Haegeli et al., 2019). Overall, carrying avalanche safety gear does not guarantee surviving an avalanche event, but it increases the chance (e.g., Hohlrieder et al., 2005; Silverton et al., 2007).

Nevertheless, studies investigating the use of avalanche safety equipment among backcountry recreationists show that a considerable share does not always carry the gear (e.g., Nichols et al., 2018; Procter et al., 2014). These studies test different features for significance with the dependent variable use of standard safety gear. Table 1 lists them and the investigated features – those with a significant association marked with *.

Sociodemographic aspects associated with carrying avalanche safety equipment include young and male residents (Nichols et al., 2018; Procter et al., 2014). According to Marengo et al. (2016), indirect avalanche experience (i.e., witnessing an avalanche accident) positively affects carrying standard safety equipment. In addition, experienced recreationists (Procter et al., 2014) with a higher self-assessed level of expertise (Nichols et al., 2018) as well as those who attended an avalanche safety course (i.e., avalanche education) (Ng et al., 2015; Nichols et al., 2018; Silverton et al., 2007), who traveled in bigger groups, and who read and understand the daily avalanche warning report (Procter et al., 2014) are more likely to use avalanche safety gear than others. In this context, it needs to be considered that the official avalanche danger information is updated daily and consists of a five-point rating scale (from 1 = low avalanche danger level to 5 =

Table 1
Compilation of all studies investigating influencing factors on using standard avalanche safety gear.

	Marengo et al. (2016)	Ng et al. (2015)	Nichols et al. (2018)	Procter et al. (2014)	Silverton et al. (2007)
Study area	Northern Italy	Wyoming, USA	Wyoming, USA	Northern Italy	Utah, USA
Sample size	214 backcountry skiers and snowboarders	104 backcountry skiers	334 backcountry skiers and snowboarders	4.333 backcountry skiers	353 backcountry recreationists (skiers, snowboarders, snowshoers, snowmobilers, out-of-bound skiers)
Features under investigation	Avalanche experience*	Avalanche education*	Age Gender Residency* Avalanche education* Skill level* Avalanche forecasts*	Age* Gender* Tours per season* Group size* Starting time*	Avalanche education*
Share using standard safety gear	82%	94%	max. 86%	81%	max. 77%

* Significant association between feature and dependent variable use of standard safety gear.

extreme avalanche danger level) and a report with detailed descriptions of the avalanche risk. According to Schwiersch (2019), who investigates risk management and accident prevention among German ski tourers, only 7% fully understand the official avalanche danger report. They either have a formal avalanche education or use an avalanche decision aid, such as the 3 × 3 filter method or DAV snowcard, similar to the Avaluator introduced by Haegeli et al. (2006). Environmental factors are hardly investigated by researchers so far. Only Nichols et al. (2018) finds out avalanche hazard forecasts to correlate with carrying safety gear: the lower the avalanche level, the lower the willingness to carry avalanche equipment. Since that forecast depends (among other things) on the weather, they therefore indirectly consider environmental factors.

In contrast to the presented studies, this study extends the previously identified influencing factors by including environmental factors (such as cloud cover, snowfall, temperature, and wind). Furthermore, region-specific factors (e.g., leaving former piste) and general aspects (e.g., kind of tour, alpine education, terrain, and avalanche information), which we identified in qualitative interviews with local experts, are added. We also include the perception of climate change among ski tourers as a factor. The underlying assumption is that ski tourers adapt their safety and prevention practices to the climate change-induced changing avalanche situation. Recent studies show that avalanche risk in the European Alps will change in frequency and magnitude depending on the altitude due to climate change (Hock et al., 2019). At lower elevations, snow avalanches will reduce in number and runout distance (Mock et al., 2017), whereas wet snow avalanche events will increase in frequency independent of altitude (Castebrunet et al., 2014). These projections coincide with investigations of avalanche events in the European Alps in the last decades (Hock et al., 2019).

We derive further factors from results on decision traps (McCammon, 2004) and risk-taking and risk management behavior (Furman et al., 2010; Haegeli et al., 2010; Haegeli et al., 2012; Schwiersch, 2019) among backcountry travelers. According to Furman et al. (2010), risk-taking propensity and heuristic principles that aim to reduce the complexity of decisions are further relevant aspects in decision-making in avalanche terrain. Backcountry recreationists establish avalanche-specific heuristics as alternative decision approaches (McCammon, 2004). Relying on these simplifying rules of thumb may result in adverse outcomes (e.g., avalanche accidents) referred to as traps when, for example, critical new information on the hazardous situation is not considered in the decision. McCammon (2004) investigates avalanche accidents in the United States and describes the following six heuristic traps: familiarity (i.e., to behave as in the same setting before), consistency (i.e., stick to the initial assessment of the situation), acceptance (i.e., engage in activities that gain respect or acceptance), the expert halo (i.e., rely on the decision of the formal or informal leader of the group), social facilitation (i.e., ski more hazardous terrain when others are present), and scarcity (i.e., the chance of being the first to ski untracked slopes). In this context, the heuristic traps are identified in a specific situation in the field where ski tourers decide whether to ski a slope or not (Furman et al., 2010). This decision is characterized by time pressure and changing environmental conditions. This study, in contrast, examines the decision-making process during planning – a situation in which time pressure does not exist. However, the heuristic familiarity is integrated as a factor in this study since it might affect the planning process.

In order to examine the decision-making process ‘carry or not’ among ski tourers, we conduct this study using decision-making theory. The theory distinguishes between three different decision environments: decision under certainty, decision under risk, and decision under uncertainty (Takemura, 2014). The decision environment in our study can be assigned to the category decision under uncertainty, since ski tourers do not have any information about the probability of the result of the decision ‘carry or not’. Furthermore, the decision-making theory divides into normative and descriptive theories (Takemura, 2014).

The normative decision theory aims to show how decisions are made on a purely rational basis. In contrast, the descriptive decision theory investigates how people make decisions based on various criteria (Laux et al., 2018). Recent studies show that backcountry recreationists do not make rational decisions (e.g., Nichols et al., 2018; Procter et al., 2014). Despite its importance for rapid location and rescue in an avalanche event, a considerable share does not always carry the avalanche safety equipment. Therefore, we embedd the analysis approach within the behavioral decision theory as part of the descriptive decision theory. According to Edwards (1961) and Payne et al. (1992), behavioral decision theory is appropriate in situations of uncertainty and in which individuals may rely on heuristics.

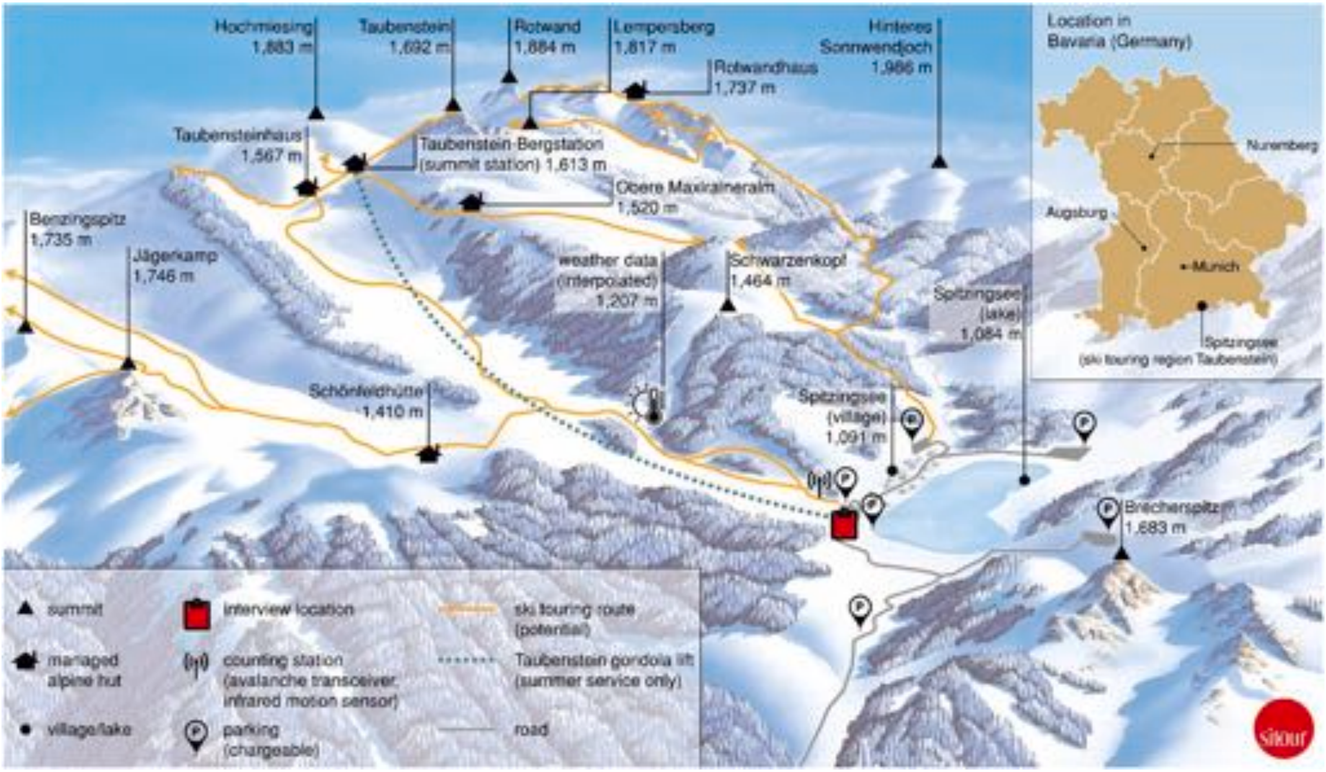
For data analysis, we use a machine learning approach. The basic suitability of such approaches for survey analysis is demonstrated, e.g., by Kern et al. (2019). Due to the theoretical embedding of our analysis and our underlying perspective of a decision-making process, we decide to use decision trees. Decision trees are the most popular machine learning algorithms among the Classification and Regression Trees (CART) (Breiman et al., 1984; Rokach and Maimon, 2010). According to Lundberg et al. (2020) tree-based models can be more interpretable than linear models due to model-mismatch effects, more accurate than neural networks, and are often applied due to their intuitive explainability and interpretability. Within the scope of our analysis, the machine learning algorithm decision tree (Section 3.4) is applied to examine how individual aspects relate to each other and which features substantially influence the decision. The statistical predictive model illustrates the importance of each influencing factor for the decision and visualizes the decision process in the form of a decision tree (Hastie et al., 2009; Kuhn and Johnson, 2013).

3. Material and methods

The study is conducted in the ski touring region Taubenstein in the Bavarian Alps (Map 1). The Taubenstein is located in the administrative district of Miesbach and is part of the regional tourism organization Alpenregion Tegernsee Schliersee (ATS). It is a former alpine ski area that stopped winter operation at the end of season 2014/15 due to economic reasons (Grauvogl, 2015). Thus, during winter, only backcountry recreationists visit it and enjoy a wide range of tours with different difficulty levels. The former lift route of the Taubensteinbahn, for example, is a supposedly secure and classic ski tour for beginners. However, the ski touring region also includes more challenging courses with various summits between Jägerkamp (1746 m), Rotwand (1884 m), and Hochmiesing (1883 m) that are accessible within a day tour (Map 1).

The region is selected as a case study since it meets crucial preconditions. First, it is one among few ski touring regions of Bavaria in which counting stations are available. There are two counting stations at the main ascent point, incorporating an infrared motion sensor and an avalanche transceiver (Map 1). Thus, measurements are differentiated between ski tourers that carry avalanche transceivers and those who do not. Shovel and probe cannot be tracked but are part of the standard avalanche safety equipment (e.g., Tremper, 2018). Thus, count data on avalanche transceiver usage provide helpful information for preparing the survey and the subsequent data analysis. Second, it is a trendy ski touring region with a large catchment area – over 4 million inhabitants, including Munich, Ingolstadt, and Rosenheim (LfStat, 2019) (Map 2). Finally, a heterogeneous group of ski tourers (i.e., beginners vs. experts and visitors vs. residents) frequents the area.

Methodologically the study is based on a mixed-method approach consisting of three phases: 1.1) As a qualitative preparation of the study, we conduct expert interviews with six local stakeholders between January and July 2020. To gather information on ski touring in general and, in particular, on the Taubenstein region for the questionnaire development, we consult the following persons: An avalanche education trainer, a mountain and ski touring guide, an area supervisor, the CEO of the regional tourism organization ATS and a representative of the DAV Section Munich (German Alpine Club). 1.2) In a quantitative analysis of



Map 1. Ski touring region Taubenstein and its location in the German state of Bavaria. *Source:* Illustration modified from sitour (2016), map based on GeoBasis-DE / BKG (2018).

the count data described in the previous paragraph, we determine the appropriate survey period by considering the seasonal pattern and the distribution of weekdays in the proportion of carrying standard safety equipment. 2) Based on the previous steps, a researcher-administered survey among 359 ski tourers is conducted in the case study region. We extend the survey data with (a) daily weather data (i.e., maximum temperature, snowfall amount, average wind velocity, and average cloud cover) of the weather information company meteoblue (2020) – interpolated for the average altitude of the ski touring region Taubenstein (1207 m) (Map 1) and; (b) daily updated avalanche danger level (Lawinenwarnzentrale, 2020). 3) We discuss the descriptive analysis results of the survey data with all experts conducting a group discussion and subsequently use the results to develop the machine learning algorithm decision tree and the interpretation of the survey results.

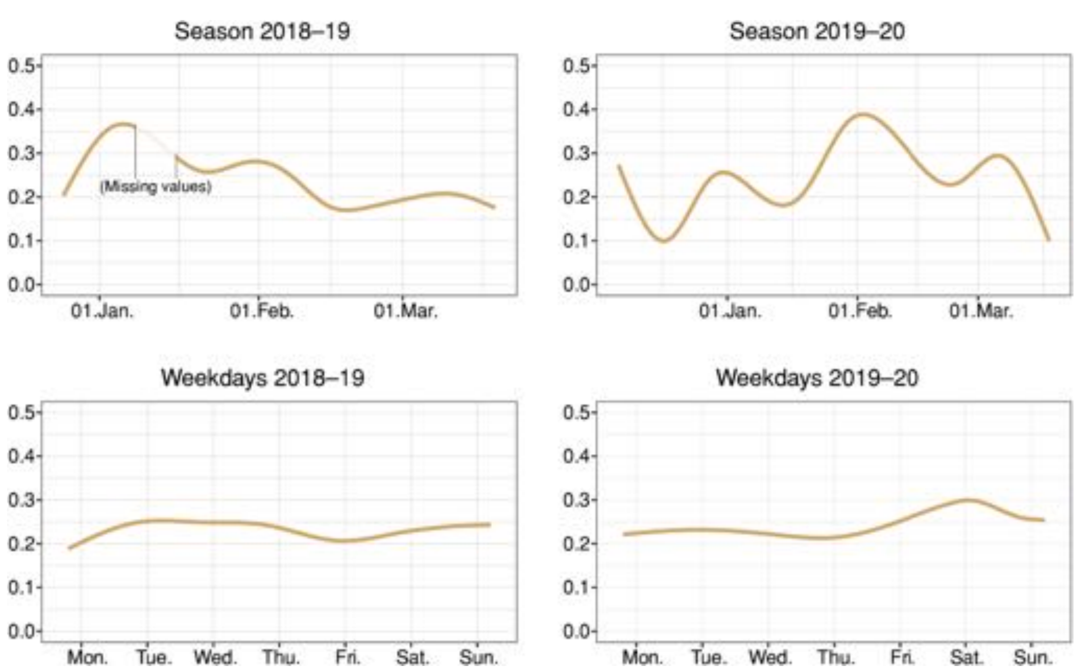


Fig. 1. Seasonal and weekly course of the proportional avalanche transceiver usage in the study area.

3.1. Pre-analysis of the count data

The pre-analysis examines the proportion of people carrying an avalanche transceiver over two winter seasons, 2018/19 and 2019/20, in the ski touring region Taubenstein (Fig. 1). For the season 2018/19, the daily data collection began on 21 December 2018 and ended on 13 April 2019 with an interruption between 7 and 15 January 2019 due to adverse weather conditions. For the season 2019/20, the data collection started on 6 December 2019 and ended on 20 March 2020. Fig. 1 shows a decrease in the proportions of carrying standard safety equipment at the end of each season and a relatively constant trend of the proportions over the weekdays for both seasons.

3.2. Survey instrument

A researcher-administered survey provides the data basis of this study. The original questionnaire is available from the following GitHub page (https://github.com/kevorks/CarryAlongOrNot). It comprises five sections that include all factors under investigation: Section one contains three questions on the respondents' route planning as well as their familiarity with the ski touring region Taubenstein (average visiting frequency per season and number of years touring the region) relating to the heuristic trap familiarity (McCammon, 2004).

Section two includes ten questions on the ski tourers' avalanche safety and prevention practices. First, we ask respondents which standard avalanche safety equipment (i.e., transceiver, probe, and shovel) they take today. A further question investigates why ski tourers do not carry their standard avalanche safety equipment on tour (e.g., depending on the avalanche danger level, the planned trip, the company (in company vs. alone)). The following three questions of this section examine aspects of avalanche prevention practices: whether and if so, how ski tourers gather information about the terrain of the planned tour and the daily updated official avalanche danger information. Furthermore, respondents indicate how often they gathered information about the avalanche danger of the last five tours (using a six-point scale from 0 = never to 5 = always). The questionnaire includes four questions on avalanche education: whether and if so when respondents took the last avalanche course and if they know and already used the avalanche decision aids DAV snowcard and 3 × 3 filter method. The last question in this section considers the group size in which respondents are on a ski tour.

The third section deals with the ski tourers' experiences. First, they indicate the year they started with ski touring and their average ski tours per season. The following two self-evaluation questions address the individual experience and risk-taking in ski touring (using a ten-point scale from 0 = no experience/risk to 10 = highest possible experience/risk). The last questions in this section consider the respondents' alpine education and their level of avalanche experience (i.e., direct, indirect, and no experience).

Section four focuses on climate change perception and reaction. First, respondents valued their opinion on how climate change affects ski touring in the Taubenstein region (using a five-point scale from 1 = no impact to 5 = severe impact). In the following two questions, respondents indicate a maximum of three specific climate change impacts and their reaction behavior to it. The questionnaire finishes with items on sociodemographic factors (i.e., age, education, gender, number of minors in the household, and residency). Before the survey, all six experts consulted for this study pre-tested the questionnaire in January 2020, resulting in minor changes to the questionnaire.

3.3. Data collection

To avoid errors and to handle rejection by respondents properly, trained interviewers surveyed the ski tourers. According to the count data's pre-analysis, weekdays do not show any effect, whereas carrying avalanche transceivers declines towards the end of the season (Fig. 1). Due to the expected higher heterogeneity of the avalanche transceiver usage, the study is undertaken at the end of the winter season 2019/2020 on thirteen days from 18 February until 8 March 2020 at the ski touring region Taubenstein. To achieve a balanced distribution of weekdays, we cover each weekday twice within the survey period – except for Monday, due to adverse weather conditions.

The questionnaire targets all German-speaking ski tourers in the Taubenstein region. Using systematic random sampling, we addressed every second available person at Parkplatz Taubensteinbahn (Map 1), which was in the ascent or descent to the ski slope and that could be identified as ski tourers by their gear. Within the survey period and between the daily survey times, between 10:30 am and 10:15 pm on weekdays and between 8:30 am and 5:30 on weekends, we conducted a final number of 359 interviews – 352 of which were fully completed (Map 2). Due to the random selection, we assume a representative sample for the survey period. As the survey ends two weeks before the first Covid-19 measures in Germany, we expect no pandemic-related effects.

3.4. Data analysis

To answer the research questions, we use a decision tree – a popular machine learning algorithm among the Classification and Regression Trees (CART) (Breiman et al., 1984; Rokach and Maimon, 2010). With this statistical approach, we can show the relative importance of all identified influencing features for the decision to 'carry or not'. Furthermore, it reflects the decision-making process and the dependence of these influencing factors on each other. That is in contrast to the classical statistical approach used in previous studies, in which statistical correlation is examined between individual influencing features and carrying avalanche safety equipment.

The decision tree is a predictive model built by dividing the feature space into three central nodes: root node, internal node, and leaf node (Hastie et al., 2009; Kuhn and Johnson, 2013). The root node (i.e., top decision node) learns to organize the tree based on the feature value splitting the entire population or a sample into two or more homogeneous sets. Internal nodes are between two nodes and thus have one incoming and at least two outgoing branches that split the node into subnodes (also called child nodes). Leaf nodes do not have branches, as they are the final decisions made by the decision tree – in our case, to 'carry or not'.

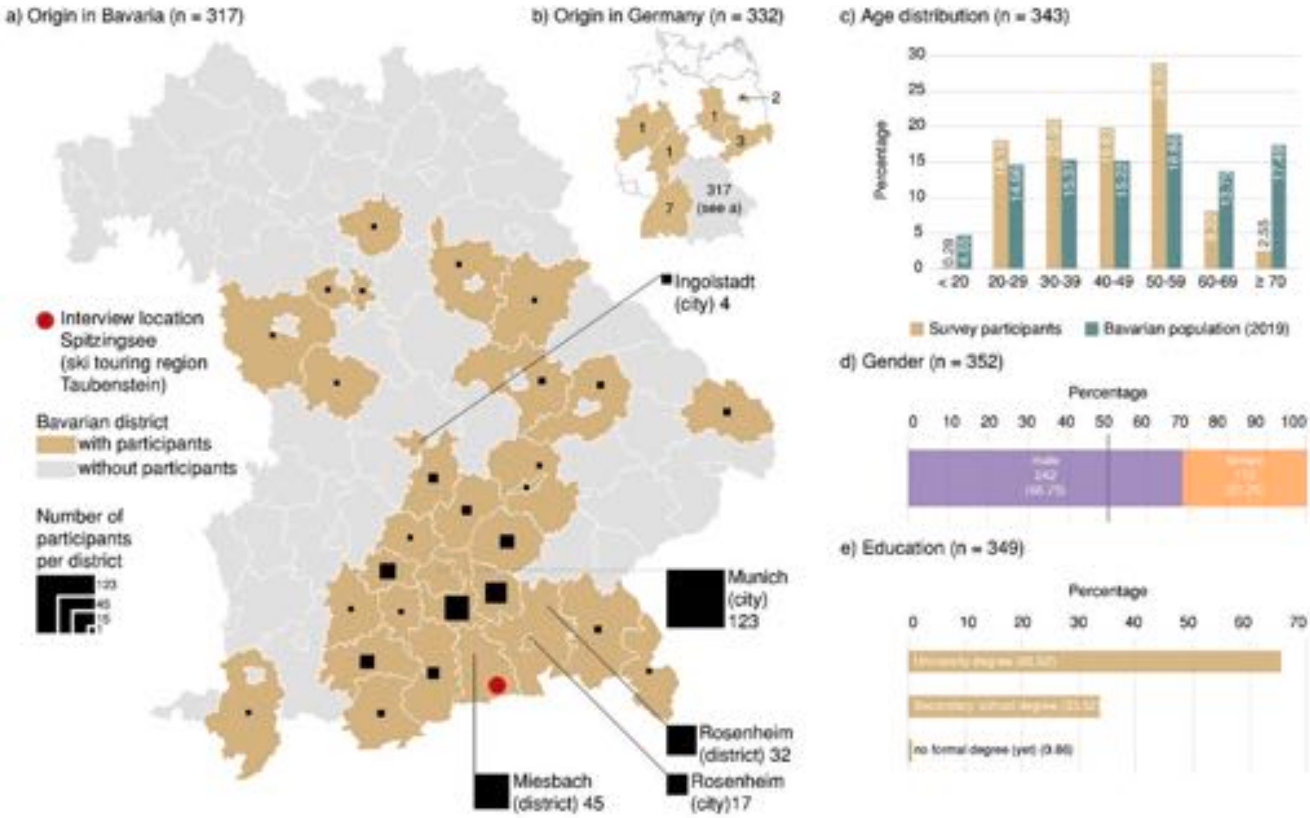
The data $T(f_i, y_i)$ consists of $i = 1, 2, \cdots, n$ observations, where f_i is the vector of $j = 1, 2, \cdots, p$ features and y_i is, in our case, the binary outcome of the dataset. First, it is necessary to determine the importance of each feature, with the most relevant feature being placed at the root node (top decision node). The further down in the decision tree, the lower the degree of impurity, which leads to a better classification or split at each node. For the splitting decision, different measures can be taken into account. This study uses the Gini index, a standard measure for categorical/binary outcomes (Breiman et al., 1984).

The Gini index quantifies the probability of a particular feature being misclassified by the model if it is randomly selected. For a binary outcome, with classes $k = 1, 2$, this measure is given by:

$$Gini(\gamma) = \sum_{k=1}^{2} \pi_{k(\gamma)} \left(1 - \pi_{k(\gamma)}\right)^2; \quad k = 1, 2$$

where $\pi_{k(\gamma)}$ is the probability of observations being classified to a particular class in node γ. The Gini index takes values between 0 and 1, where 0 denotes that all observations belong to a specific class, and 1 denotes that the observations are randomly distributed across different classes. Therefore, while building the decision tree, the feature with the lowest Gini index is selected as a root node. Determining the best split, the CART algorithm takes a recursive approach for every sub-tree rooted at the new nodes (Zhang and Singer, 2010). The algorithmic steps work in detail as follows: Let T be the training set.

grow(T):



Map 2. Catchment area of the ski touring region Taubenstein including sociodemographic facts of the sample. *Source:* Map based on GeoBasis-DE / BKG (2018).

(1) Find the feature *f*, using the Gini index that contributes the maximum information about the class labels.
(2) Divide *T* into subsets (T_j), each characterized by a different value of *f*.
(3) For each T_j: If all observations in T_j belong to the same class, then create a leaf node labeled with this class; otherwise, apply the same procedure recursively to each training subset: *grow*(T_j).

The tree growing process can eventually lead to many leaf nodes. In other words, the decision tree can overfit the training data. To avoid overfitting, the minimum number of cases per node and pruning of cost-complexity are introduced as stopping criteria. The best sub-tree can be found by cutting back tree branches. Once an optimal decision tree is found, the models' prediction is evaluated based on the test data and the predictions' accuracy. For more in-depth understanding, see Breiman et al. (1984).

The dataset consists of 319 observations (the model excludes all observations with missing values in one of the models' features) and 28 features, including the outcome feature. A table that lists all features and the respective categories included in the analysis and a descriptive analysis of all features concerning central tendencies and measures of dispersion is available at the project's GitHub page (https://github.com/kevorks/CarryAlongOrNot).

In order to evaluate the performance of our model, we use a cross-validation approach. The *k*-fold Cross Validation splits the training data into *k* equally sized subsamples – in our case $k = 10$). For each fold, we use 90% of the subsamples as training data and the other 10% of the subsamples as test data, as demonstrated in Fig. 2a. Furthermore, for each fold, we evaluate the performance of our model and calculate the prediction's accuracy (see Fig. 2b). Finally, we calculate the overall mean accuracy of the prediction. Our model has an average accuracy of 76% with a standard deviation of 5% (indicating that the accuracy can differ ±5%). The advantage of the applied *k*-fold Cross Validation approach is that the model uses all observations for both: training and

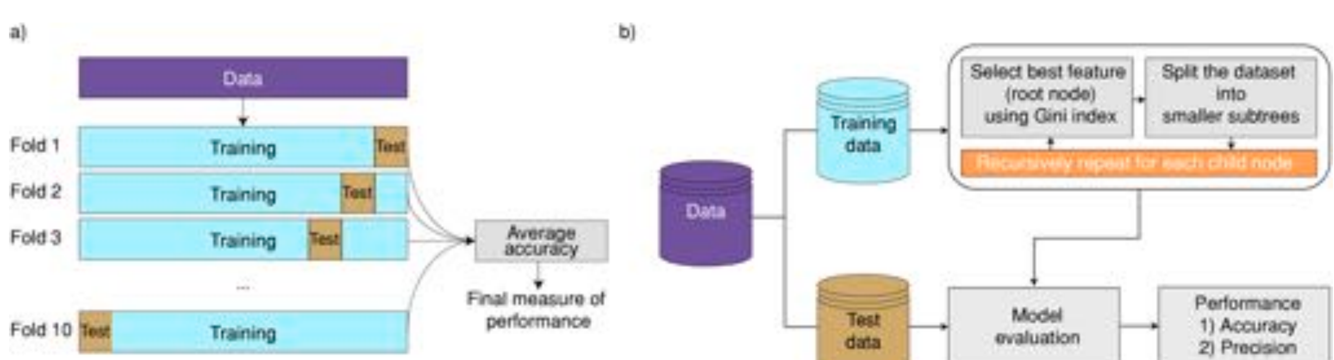


Fig. 2. The models' generation process: a) for the entire data set and; b) for each fold.

test. Also, each observation is used for the validation exactly once.

Additionally, we perform a sensitivity analysis to quantify the performance of our model. Therefore, we calculate the ROC curve (Receiver Operating Characteristics curve), where the AUC (Area Under the Curve) shows how much the model can distinguish between classes. The AUC value varies between 0 and 1, i.e., 0% and 100%, where 100% represents the perfect and 0% the worst separability measure. An AUC of 50% means that the model has no class separation capacity at all. The AUC of our model is 76.2%, which means there is a 76.2% chance that the model predicts the class not carrying as not carrying and the class carrying along as carrying along.

For data analysis, we use the open-source software R (R Core Team, 2020). We estimate the decision tree model with the package 'rpart' (Therneau and Atkinson, 2019). Furthermore, we perform a pre-analysis to test for collinearity of the metric and categorical features. The collinearity of metrical features is tested using the package 'stats' (R Core Team, 2020). For categorical features, we use our function, following Cohen (1988). None of the features are excluded from the analysis. The full reproducible R script, all codes, and additional material (e.g., original questionnaire, figures on collinearity of the features, table of the models' features, descriptive analysis of all features concerning central tendencies and measures of dispersion, the figure of the sensitivity analysis) are available on the following GitHub page: https://github.com/kevorks/CarryAlongOrNot.

4. Results

In the first step, the algorithm calculates the relative importance of each feature for the decision to carry standard avalanche safety equipment or not (Fig. 3). Based on this, the algorithm excludes those features from the generation process of the decision tree that do not show any importance for the decision (i.e., the features avalanche education, gender, minors in household, residency, and university degree).

In the next step, the algorithm creates the decision tree (Fig. 4) taking into account the results of Fig. 3. Due to stopping criteria, some features with high importance values (e.g., snowfall, age) do not appear in the decision tree. The feature snowfall, for example, is not part of the decision tree due to its high correlation with the other weather features (see supplementary information on the GitHub page). The exclusion of the feature age, which is a continuous feature, can be explained by the decision tree's difficulty to identify thresholds to classify the outcome into not carrying or carrying along.

The decision tree displays the decision-making process and its underlying features. Any sequence of tests along the path from the root node to a leaf node represents an if-then rule. Therefore, the algorithm labels a given decision (i.e., carrying standard avalanche safety equipment) with this yes or that no class. The decision-making process always starts at the top decision node avalanche danger level and ends with the final decision carry along or not at the bottom. The percent values on each node show the respective share of the entire sample. In contrast to the relative importance of each feature for the decision 'carry or not' (Fig. 3), the outcome of the decision tree depends on all previous decisions (i.e., features), whereby the importance of features within each decision process decreases from top to down. The likelihood to carry standard avalanche safety equipment (outcome) increases from the left to the right site.

The following section exemplarily describes two sets of rules for the carrying along class obtained from the decision tree – one at the left and one at the right edge. It includes the if-then rule, a short description, and the respective share of each branch:

If-then rule: *If* Avalanche danger level = yes, AND Cloudiness ≥97%, AND Self-assessment risk-taking ≥4 *then* Carrying along, else Not carrying.
Description: Ski tourers in this class carry the standard avalanche safety equipment depending on the avalanche danger level and under cloudy skies. Furthermore, they can be characterized as rather risk-tolerant.
Share: 2%.
If-then rule: *If* Avalanche danger level = no, AND Avalanche information frequency = always *then* Carrying along, *else* Not carrying.
Description: Ski tourers carry the standard avalanche safety equipment independent of the avalanche danger level and always gather information about the tour's avalanche danger.
Share: 58%.

According to the different decision tree branches (Fig. 4), we classify ski tourers into three different types concerning their carrying behavior

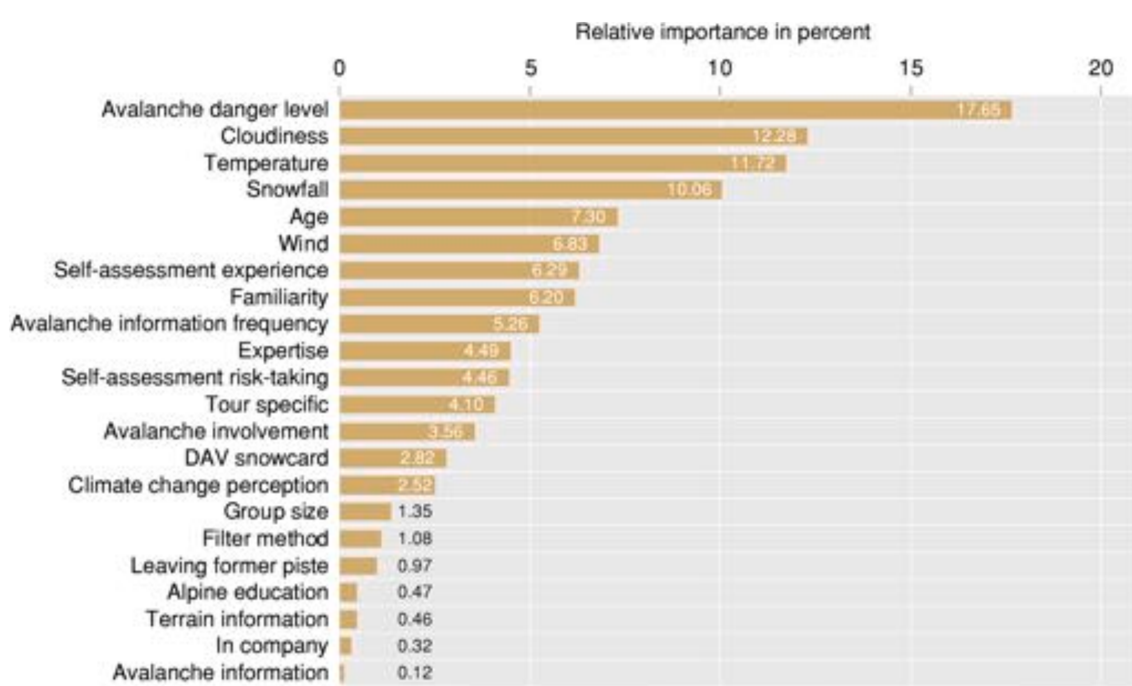


Fig. 3. Models' defining features and the corresponding importance.

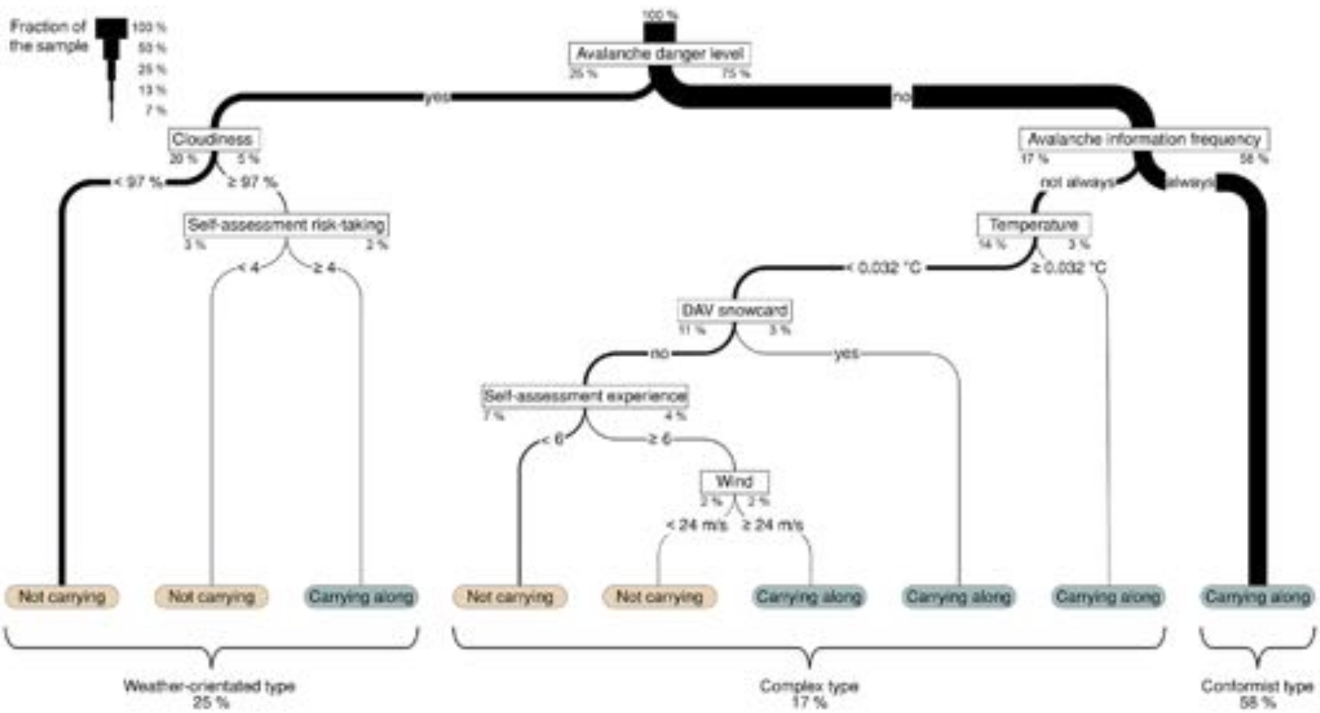


Fig. 4. Decision tree model result.

of standard avalanche safety equipment. The following classification illustrates the different decision-making processes – the main reason we apply the machine learning algorithm decision tree in this study.

Weather-oriented (25%): Ski tourers in this class tend to leave the equipment at home and decide primarily on environmental factors, such as avalanche danger level and weather conditions. According to previous studies results, a considerable share of backcountry recreationists does not carry the equipment. Identifying them as weather-oriented could explain that behavior for the first time.

Complex (17%): Ski tourers consider up to six different features in their decision process in this class. Furthermore, a clear tendency to carry the safety equipment (8%) or not (9%) is not visible. The decision process is rather complex since it not only dependent on environmental factors (i.e., avalanche danger level, weather conditions) and ski touring experience or prevention practices (i.e., using avalanche decision aid and information on the tour's avalanche danger for tour planning).

Conformist (58%): This type is already known in research. The majority of ski tourers behave compliant with the safety rule to carry standard avalanche equipment on every tour. This conformity also becomes clear by looking at the decision process in which respondents are always informed about the tour's avalanche danger – another critical prevention practice in a ski tour planning process.

5. Discussion

Results show that ski tourers can be divided into three types (weather-oriented, complex, and conformist, see Fig. 4) according to their carrying behavior of avalanche safety gear and the underlying decision process that is influenced by different features.

Weather-oriented ski tourers primarily base their decision 'carry or not' on environmental factors, such as the avalanche danger level and weather conditions (i.e., cloudiness). A considerable share of respondents (25%) decides to 'carry or not' depending on the avalanche danger level. Due to the small number of answers, a more precise statement at which avalanche danger levels ski tourers 'carry or not' is not feasible. Nichols et al. (2018) finds out that a low avalanche danger level negatively impacts the likelihood to carry avalanche safety gear. The wrong interpretation of the avalanche hazard tables leading to a false sense of safety at the avalanche danger levels low and moderate explains this behavior (Rainer et al., 2008). Statistics from the last two decades on avalanche accidents per danger level in Switzerland show that standard avalanche equipment should be carried independently of the avalanche danger levels (SLF, 2020). In a second step, the decision of weather-oriented ski tourers depends on weather conditions. Some ski tourers do not carry the standard equipment under sunny skies (<97%). In this context, it needs to be kept in mind that weather conditions are negligible as influencing factors in avalanche accidents (Atkins, 2000) since avalanches also occur on days with sunny skies. During cloudy conditions, the risk tolerance of ski tourers also plays a role in the decision. Thus, rather risk-tolerant ski tourers (≥4) show a higher willingness to carry the equipment. The need for security can explain this due to higher risk tolerance. According to Eyland (2016) and Haegeli et al. (2019), this relation can also be the other way round in the sense that carrying avalanche devices may increase risk-taking propensity. Overall, it becomes evident that risk propensity is crucial in decision-making in avalanche terrain (McClung, 2002).

A decision process with various factors characterizes the complex type. The avalanche danger level does not play any role in the decision. Its irrelevance can be explained by the fact that ski tourers of this type are not always informed about the current avalanche danger. They base their decision on weather conditions and tend to carry the avalanche gear in warm temperatures (≥0.032 °C) or windy days (≥24 m/s). Snowfall is not part of the decision tree, but its negative correlation with temperature (see supplementary information on the GitHub page) suggests that the likelihood to carry increases with more snowfall. Such a rule of thumb based on weather conditions is precarious since avalanches also occur on days with low temperatures, wind, or snowfall (Atkins, 2000). Furthermore, on-site weather conditions are challenging to assess from a distance. Thus, carrying standard avalanche safety gear should not be attached to weather conditions. During cold temperatures, ski tourers who already used the avalanche decision aid DAV snowcard are more likely to carry the minimum equipment. The use of avalanche decision aids indicates that respondents attended an avalanche course and thus, reflects a basic level of avalanche education (Haegeli et al., 2006). This education can be why ski tourers that use the decision aid tend to carry the avalanche equipment. If they do not use the DAV snowcard, respondents that evaluate themselves as experienced in ski touring ($\geq$6) are more likely to carry the standard avalanche safety equipment. This finding confirms Bianchi (2014), Nichols et al. (2018), and Procter et al. (2014), who find out a positive correlation between the level of expertise and the likelihood to carry standard rescue equipment.

Conformists are those ski tourers that act consistently with the rules and recommendations taught in avalanche education courses. They are already known in research, where the share varies between 77 and 94% (see Table 1).

The factors climate change perception and avalanche education are not part of the decision tree and thus, do not influence the decision process of the identified types. Regarding climate change perception, the different temporal dimensions between the long-term process of climate change and the ad hoc decision to ‘carry or not’ can be why this feature is not relevant in the decision. However, studies predict a changing avalanche risk in mountain areas (e.g., Hock et al., 2019) that affects future ski tour planning and should be part of training and education courses. The model excludes the feature avalanche education during the generation process of the decision tree since it does not show any importance for the decision. This result considerably differs from various studies that determined avalanche education (i.e., take an avalanche safety course) to be of high significance in this context. According to Ng et al. (2015), Nichols et al. (2018), and Silverton et al. (2007), those who attended an avalanche course are more likely to carry the minimum safety equipment. However, this correlation neither deters backcountry recreationists from skiing steep slopes nor preventing avalanche fatalities (McCammon, 2000). One reason for the different outcomes can be our features’ definition that avalanche education only applies if the course took place in the last six years. We determine this threshold after the group discussion with the experts. They argue that participants forget provided content over the years. Therefore, they recommend repeating avalanche education courses after six years. The feature leaving the former piste, which is specific to the Taubenstein region, does not show any importance within the decision process – similar to the feature residency that the model excludes. We conclude that the decision-making process is driven by general aspects and independent of local or geographical issues.

Using a machine learning approach instead of individually testing for statistical significance (e.g., Ng et al., 2015; Silverton et al., 2007), this study reveals that environmental aspects (e.g., avalanche danger level, weather conditions) are more decisive than sociodemographic features. All sociodemographic aspects investigated in this study do not show any relevance in the decision-making process to ‘carry or not’. This finding enhaces Nichols et al. (2018) and Procter et al. (2014) and shows that environmental aspects are part of the perception of ski tourers. So far, previous studies exclusively investigate quantifiable aspects, but the results of our study show that the ski tourers’ perception is of high importance in the decision process.

6. Conclusion

This study follows an explorative approach that aims to understand and display the decision-making process on carrying standard avalanche safety equipment among ski tourers. The results do not claim to be representative for all ski touring regions in the German Alps but can be seen as an essential contribution to the content-related and methodological international discussion.

The main finding is that ski tourers can be classified into the following three types: weather-oriented, complex, and conformist. This classification is based on the ski tourers’ final decision to ‘carry or not’ and the respective decision process that differs among these types. Furthermore, the results show that in contrast to previous studies (Marengo et al., 2016; Ng et al., 2015; Nichols et al., 2018; Procter et al., 2014; Silverton et al., 2007), a) the decision needs to be considered as a process and; b) the decision does not depend on personal traits alone but also on environmental factors. Research may have underestimated the importance of these factors (i.e., avalanche danger level and weather conditions) so far. The weather-oriented type, who especially considers avalanche danger and weather conditions in decision-making, can be seen as an indicator for the decision strategy heuristics that might lead ‘in some cases […] to inappropriate […] or inconsistent […] decisions’ (Takemura, 2014). These environmental heuristics refer to the planning phase of a ski tour and cannot be compared with the avalanche heuristics identified by McCammon (2004) that refer to a specific situation in the field.

In our study, only 51% of respondents took an avalanche course in the last six years. This low share may be one reason for the importance of environmental heuristics in the decision process since Furman et al. (2010) and Haegeli et al. (2010) find out that the likelihood to rely on heuristics can be reduced, among others, through avalanche education. Concerning the classification of ski tourers, actors involved in ski touring should concentrate on the weather-oriented type. They account for 25%, and the carrying behavior not carrying can be changed through awareness-raising campaigns and adapted education programs that treat these environmental heuristics. Increased awareness and education may lead to more ski tourers that act compliant with the safety principle to carry standard avalanche safety equipment on every tour (conformist type).

Apart from these results, this study and its methodological approach also contribute to research. Compared to previous studies in this field that apply a classical statistical approach by testing influencing features individually for statistical significance for the decision (e.g., Nichols et al., 2018; Procter et al., 2014), this study takes a new methodological approach and considers ‘carry or not’ as a decision process. Therefore, the analysis is based on the behavioral decision theory and uses the machine learning algorithm decision tree to illustrate the decision process and examine the relative importance of each influencing feature for the decision to ‘carry or not’. Due to its high accuracy (76%), the model can be considered well-constructed and can predict the decision-making process – an incentive to use this methodological approach in other decision processes in avalanche terrain.

We identify two limitations regarding the research question which factors are decisive for the decision of ski tourers for or against carrying the standard equipment: First, the study is a regional example of an area not situated in high alpine terrain. It is therefore not feasible to make generalized statements about other study areas and their ski tourers. Thus, the question remains open whether similar decision-making processes also influence ski tourers at other locations. However, to answer this question, the presented approach allows transferability. Second, despite intensive preparation and precise planning of the survey period (see chapter 3), the survey is time-limited and does not cover a complete season. An extension of the survey period and a concomitant increase in the sample size could improve the overall robustness of the results. However, the tendential importance of the identified factors and their interdependence across the decision tree should be consistent – as illustrated by the models’ high accuracy (76%).

For future research, we encourage comparative studies of other backcountry activities in different regions (e.g., higher elevation) and countries to improve the models’ learning and accuracy. Such large-scale quantitative surveys, covering the presented influence factors, should be conducted either during the whole winter season or in various seasons. Consequently, the model would probably cover, among others, seasonal variations regarding weather conditions, avalanche danger levels, and avalanche transceiver usage even better. Moreover, this enables to further investigate the two new types (weather-oriented and complex), their decision processes, and the dominant environmental factors interpreted as decision heuristics. Future research should also investigate the use of advanced avalanche devices, such as avalanche airbag or AvaLung™, since they have a scientifically proven importance regarding the chance to survive an avalanche event. A meaningful statistical investigation of the decision to carry these additional devices is complex, as they still are underrepresented in use (e.g., Bianchi, 2014; Ng et al., 2015; Procter et al., 2014). Finally, the counting stations presented in chapter 3.1, which automatically record the share of avalanche transceiver beams in total contacts on various locations in the Alpine region, have enormous potential for further statistical evaluations and comparative analyses.

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.

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References

Atkins, D., 2000. Human factors in avalanche accidents. Paper presented at the International Snow Science Workshop, Big Sky, Montana, United States, October 2–6.
Bianchi, G., 2014. Pilotstudie: Befragung von Freeridern in Schweizer Schneesportgebieten. bfu-Grundlagen, Bern, 28 pp. Accessed 23 July 2020.
Binder, S., 2019. SKIMO Pressekonferenz 2019: Skibergsteigen. News. http://www.skimo.at/skibergsteigen/189248/skimo-pressekonferenz-2019/. Accessed 10 August 2020.
Boyd, J., Haegeli, P., Abu-Laban, R.B., Shuster, M., Butt, J.C., 2009. Patterns of death among avalanche fatalities: a 21-year review. Can. Med. Assoc. J. 180 (5), 507–512.
Breiman, L., Friedman, J., Stone, C.J., Olshen, R.A., 1984. Classification and Regression Trees, Repr ed. Taylor & Francis, Boca Raton.
Brugger, H., Durrer, B., Adler-Kastner, L., Falk, M., Tschirky, F., 2001. Field management of avalanche victims. Resuscitation 51 (1), 7–15.
Brugger, H., Etter, H.J., Zweifel, B., Mair, P., Hohlrieder, M., Ellerton, J., Elsensohn, F., Boyd, J., Sumann, G., Falk, M., 2007. The impact of avalanche rescue devices on survival. Resuscitation 75 (3), 476–483.
Castebrunet, H., Eckert, N., Giraud, G., Durand, Y., Morin, S., 2014. Projected changes of snow conditions and avalanche activity in a warming climate: the French Alps over the 2020–2050 and 2070–2100 periods. Cryosphere 8 (5), 1673–1697.
Cohen, J., 1988. Statistical Power Analysis for the Behavioral Sciences, second ed. Lawrence Erlbaum Associates, Hillsdale, N.J.
Edwards, W., 1961. Behavioral decision theory. Annu. Rev. Psychol. 12 (1), 473–498.
Eyland, T., 2016. What is the risk threshold that backcountry enthusiasts are willing to accept and how does their perception align with the actual risk involved? Paper presented at the International Snow Science Workshop, Breckenridge, Colorado, United States, October 3–7.
Falk, M., Brugger, H., Adler-Kastner, L., 1994. Avalanche survival changes. Nature 368 (6466), 21.
Frühauf, A., Hardy, W.A.S., Pfoestl, D., Hoellen, F.-G., Kopp, M., 2017. A qualitative approach on motives and aspects of risks in freeriding. Front. Psychol. 8, 1998.
Furman, N., Shooter, W., Schumann, S., 2010. The roles of heuristics, avalanche forecast, and risk propensity in the decision making of backcountry skiers. Leisure Sci. 32 (5), 453–469.
GeoBasis-DE – Geodatendienste, BKG – Bundesamt für Kartographie und Geodäsie, 2018. Digitale Geodaten. Verwaltungsgebiete. Bundesamt für Kartographie und Geodäsie. https://gdz.bkg.bund.de/index.php/default/digitale-geodaten/verwaltungsgebiete.html. Accessed 22 June 2018.
Grauvogl, S., 2015. Ski-Aus am Taubenstein: Bahn stellt Betrieb ein. https://www.merkur.de/lokales/region-miesbach/ski-aus-taubenstein-bahn-stellt-betrieb-gondeln-fahren-noch-sommer-4933902.html.
Grissom, C.K., Radwin, M.I., Harmston, C.H., Hirshberg, E.L., Crowley, T.J., 2000. Respiration during snow burial using an artificial air pocket. J. Am. Med. Assoc. 283 (17), 2266–2271.
Groves, M.R., Varley, P.J., 2020. Critical mountaineering decisions: technology, expertise and subjective risk in adventurous leisure. Leisure Studies 39 (5), 706–720.
Haegeli, P., Falk, M., Brugger, H., Etter, H.-J., Boyd, J., 2011. Comparison of avalanche survival patterns in Canada and Switzerland. Can. Med. Assoc. J. 183 (7), 789–795.
Haegeli, P., Falk, M., Procter, E., Zweifel, B., Jarry, F., Logan, S., Kronholm, K., Biskupič, M., Brugger, H., 2014. The effectiveness of avalanche airbags. Resuscitation 85 (9), 1197–1203.
Haegeli, P., Gunn, M., Haider, W., 2012. Identifying a high-risk cohort in a complex and dynamic risk environment: out-of-bounds skiing – An example from avalanche safety. Prev. Sci. 13 (6), 562–573.
Haegeli, P., Haider, W., Longland, M., Beardmore, B., 2010. Amateur decision-making in avalanche terrain with and without a decision aid: a stated choice survey. Nat. Hazards 52 (1), 185–209.
Haegeli, P., McCammon, I., Jamieson, B., Israelson, C., Statham, G., 2006. The avaluator – A canadian rule-based avalanche decision support tool. Paper presented at the International Snow Science Workshop, Telluride, Colorado, United States, October 1–6.
Haegeli, P., Rupf, R., Karlen, B., 2019. Do avalanche airbags lead to riskier choices among backcountry and out-of-bounds skiers? J. Outdoor Recreat. Tour. 100270.
Hastie, T., Tibshirani, R., Friedman, J.H., 2009. The elements of statistical learning. Data mining, inference, and prediction, second ed., corrected at 11th printing 2016 ed. Springer, New York, NY.
Hock, R., Rasul, G., Adler, C., Cáceres, B., Gruber, S., Hirabayashi, Y., Jackson, M., Kääb, A., Kang, S., Kutuzov, S., Milner, A., Molau, U., Morin, S., Orlove, B., Steltzer, H., 2019. High Mountain Areas. In: Pörtner, H.-.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., Petzold, J., Rama, B., Weyer, N.M. (Eds.), IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, Geneva, pp. 131–202.
Hohlrieder, M., Brugger, H., Schubert, H.M., Pavlic, M., Ellerton, J., Mair, P., 2007. Pattern and severity of injury in avalanche victims. High Altitude Med. Biol. 8 (1), 56–61.
Hohlrieder, M., Mair, P., Wuertl, W., Brugger, H., 2005. The impact of avalanche transceivers on mortality from avalanche accidents. High Altitude Med. Biol. 6 (1), 72–77.
Jażdżewska, I., 2016. Ski touring in Poland: Who takes part in this form of specialised tourism? How do they take part and why? Turyzm/Tourism 26 (1), 61–69.
Kern, C., Klausch, T., Kreuter, F., 2019. Tree-based machine learning methods for survey research. Survey Res. Methods 13 (1), 73–93.
Kuhn, M., Johnson, K., 2013. Applied Predictive Modeling, Corrected at 5th printing 2016 ed. Springer, New York.
Laux, H., Gillenkirch, R.M., Schenk-Mathes, H.Y. (Eds.), 2018. Entscheidungstheorie. Springer Berlin Heidelberg, Berlin, Heidelberg.
Lawinenwarnzentrale, 2020. Lawinenlagebericht. www.lawinenwarndienst-bayern.de. Accessed 17 August 2020.
LfStat – Bayerisches Landesamt für Statistik, 2019. Zahlen zum Bevölkerungsstand in Bayern 2019. https://www.statistik.bayern.de/statistik/gebiet_bevoelkerung/bevoelkerungsstand/index.html.
Lundberg, S.M., Erion, G., Chen, H., DeGrave, A., Prutkin, J.M., Nair, B., Katz, R., Himmelfarb, J., Bansal, N., Lee, S.-I., 2020. From local explanations to global understanding with explainable AI for trees. Nat. Mach. Intell. 2 (1), 56–67.
Marengo, D., Dellavedova, P., Monaci, M.G., Miceli, R., 2016. Direct and indirect avalanche experiences among backcountry skiers: Relationships with risk perception and use of safety gear. Paper presented at the International Snow Science Workshop, Breckenridge, Colorado, United States, October 3–7.
McCammon, I., 2000. The Role of Training in Recreational Avalanche Accidents in the United States. Paper presented at the International Snow Science Workshop, Big Sky, Montana, United States, October 2–6.
McCammon, I., 2004. Heuristic traps in recreational avalanche accidents: evidence and implications. Avalanche News 68, 1–10.
McClung, D., Schaerer, P., 2006. The Avalanche Handbook, third ed., 1. print ed. The Mountaineers Books, Seattle Wash.
McClung, D.M., 2002. The elements of applied avalanche forecasting, Part I: the human issues. Nat. Hazards 25, 111–129.
McIntosh, S.E., Grissom, C.K., Olivares, C.R., Kim, H.S., Tremper, B., 2007. Cause of death in avalanche fatalities. Wilderness Environ. Med. 18 (4), 293–297.
meteoblue, 2020. Weather data on daily basis. https://content.meteoblue.com/. Accessed 25 August 2020.
Mock, C.J., Carter, K.C., Birkeland, K.W., 2017. Some perspectives on avalanche climatology. Ann. Am. Assoc. Geogr. 107 (2), 299–308.
Ng, P., Smith, W.R., Wheeler, A., McIntosh, S.E., 2015. Advanced avalanche safety equipment of backcountry users: current trends and perceptions. Wilderness Environ. Med. 26 (3), 417–421.
Nichols, T.B., Hawley, A.C., Smith, W.R., Wheeler, A.R., McIntosh, S.E., 2018. Avalanche safety practices among backcountry skiers and snowboarders in Jackson Hole in 2016. Wilderness Environ. Med. 29 (4), 493–498.
Niedermeier, M., Gatterer, H., Pocecco, E., Frühauf, A., Faulhaber, M., Menz, V., Burtscher, J., Posch, M., Ruedl, G., Burtscher, M., 2020. Mortality in different mountain sports activities primarily practiced in the winter season—a narrative review. Int. J. Environ. Res. Public Health 17 (1), 259.
Niedermeier, M., Ruedl, G., Burtscher, M., Kopp, M., 2019. Injury-related behavioral variables in alpine skiers, snowboarders, and ski tourers—a matched and enlarged re-analysis. Int. J. Environ. Res. Public Health 16 (20), 3807.
Payne, J.W., Bettman, J.R., Johnson, E.J., 1992. Behavioral decision research: a constructive processing perspective. Annu. Rev. Psychol. 43 (1), 87–131.
Plank, A., 2016. The hidden risk in user-generated content: An investigation of ski tourers' revealed risk-taking behavior on an online outdoor sports platform. Tourism Manage. 55, 289–296.
Procter, E., Strapazzon, G., Dal Cappello, T., Castlunger, L., Staffler, H.P., Brugger, H., 2014. Adherence of backcountry winter recreationists to avalanche prevention and safety practices in northern Italy. Scand. J. Med. Sci. Sports 24 (5), 823–829.

Procter, E., Strapazzon, G., Dal Cappello, T., Zweifel, B., Würtele, A., Renner, A., Falk, M., Brugger, H., 2016. Burial duration, depth and air pocket explain avalanche survival patterns in Austria and Switzerland. Resuscitation 105, 173–176.
R Core Team, 2020. R: A language and environment for statistical computing. http://www.r-project.org/index.html.
Rainer, B., Frimmel, C., Sumann, G., Brugger, H., Kinzl, J.F., Lederer, W., 2008. Correlation between avalanche emergencies and avalanche danger forecast in the alpine region of Tyrol. Eur. J. Emergency Med. 15 (1), 43–47.
Reynier, V., Vermeir, K., Soule, B., 2014. Social representations of risks among winter sports participants: a focus on the influence of sports practice and style in the French Alps. Sport Soc. 17 (6), 736–756.
Rokach, L., Maimon, O., 2010. Classification Trees. In: Maimon, O., Rokach, L. (Eds.), Data Mining and Knowledge Discovery Handbook. Springer, US, Boston, MA, pp. 149–174.
Schwiersch, M., 2019. Risikomanagement und Unfallprävention im Bergsport. Ergebnisse alpiner Feldforschung. In: Berghold, F., Brugger, H., Burtscher, M., Domej, W., Durrer, B., Fischer, R., Paal, P., Schaffert, W., Schobersberger, W., Sumann, G. (Eds.), *Alpin- und Höhenmedizin*, 2, Auflage ed. Springer, Berlin Heidelberg, Berlin, Heidelberg, pp. 141–150.
Silverton, N.A., McIntosh, S.E., Kim, H.S., 2007. Avalanche safety practices in Utah. Wilderness Environ. Med. 18 (4), 264–270.
sitour, 2016. Werbung in Skigebieten – Panoramatafeln. sitour-werbe gmbh. https://www.sitour.de/werbung-in-skigebieten/analoge-werbetraeger/panoramatafeln/ (Kindly made available for use). Accessed 5 October 2020.
SLF – Institut für Schnee- und Lawinenforschung, 2020. Lawinenunfälle pro Gefahrenstufe. https://www.slf.ch/de/lawinen/unfaelle-und-schadenlawinen/langjaehrige-statistiken.html. Accessed 28 October 2020.
Soule, B., Reynier, V., Lefevre, B., Boutroy, E., 2017. Who is at risk in the French mountains? Profiles of the accident victims in outdoor sports and mountain recreation. J. Mountain Sci. 14 (8), 1490–1499.
Takemura, K., 2014. Behavioral Decision Theory. Springer, Japan, Tokyo.
Therneau, T., Atkinson, B., 2019. rpart: Recursive Partitioning and Regression Trees.: R package version 4.1-15. https://CRAN.R-project.org/package=rpart.
Tremper, B., 2018. Staying Alive in Avalanche Terrain, third ed. Mountaineers Books, Seattle.
Van Tilburg, C., Grissom, C.K., Zafren, K., McIntosh, S., Radwin, M.I., Paal, P., Haegeli, P., Smith, W.R., Wheeler, A.R., Weber, D., Tremper, B., Brugger, H., 2017. Wilderness medical society practice guidelines for prevention and management of avalanche and nonavalanche snow burial accidents. Wilderness Environ. Med. 28 (1), 23–42.
Volken, M., Schnell, S., Wheeler, M., 2007. Backcountry Skiing: Skills for Ski Touring and Ski Mountaineering. The Mountaineers Bock, Seattle.
Zhang, H., Singer, B.H., 2010. Recursive Partitioning and Applications, second ed. Springer, New York.