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Do avalanche airbags lead to riskier choices among backcountry and out-of-bounds skiers?

Pascal Haegeli[a,*], Reto Rupf[b], Barbara Karlen[b]

[a] School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, BC, V5A 1S6, Canada
[b] Institute of Natural Resource Sciences, Zurich University of Applied Sciences, Wädenswil, Switzerland

A R T I C L E I N F O

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A B S T R A C T

While the effectiveness of airbags for reducing mortality in avalanche involvements has been examined in various studies, the question of whether the added safety benefit might lead to increased risk-taking – a phenomenon referred to as risk compensation or risk homeostasis – has only been tackled by a few researchers. Building on the existing research on airbags, risk compensation, and stated terrain preferences in winter backcountry recreation, we conducted an extensive online survey including a discrete choice experiment to approach the topic of avalanche airbags and risk compensation from multiple perspectives. Our study sample consists of 163 airbag owners and 243 non-owners mainly from Switzerland, Germany, and Austria. The analyses of the survey responses provide both indirect and direct evidence that risk compensation in response to avalanche airbags is likely within at least certain segments of the recreational backcountry and out-of-bounds skiing population. Initial indirect evidence on risk compensation is provided by examining participants' responses to airbag attitude and use questions using the framework of Hedlund (2000). The stated terrain preferences in our discrete choice experiment with and without airbags indicate that non-owners of airbags might make more aggressive terrain choices when they are given an airbag, whereas the preference patterns of owners did not change when the airbag was taken away from them. Finally, our analysis of avalanche involvement rates with and without airbags offers the most direct evidence that more thrill-seeking backcountry users are taking higher risks when equipped with airbags. The paper concludes with a discussion that highlights that the potential for risk compensation is not a strong argument against the use of avalanche airbags.

Management implications:

- If properly used, avalanche airbags are an effective avalanche safety device for reducing the risk of critical burials and death.
- Considerable indirect and direct evidence exists that highlights that avalanche airbags likely lead to risk compensation within at least some segments of the recreational backcountry and out-of-bounds skiing population.
- Risk-taking in the backcountry is a personal choice, but recreationalists should have the necessary information about the direct and potential indirect effects of safety devices to make informed decisions.
- The topic of risk compensation should be included in avalanche awareness courses and discussed in avalanche airbag support documentation and user manuals to increase the awareness of the potential among users.
- Additional avalanche accident research should be conducted to better understand the circumstances when the effectiveness of airbags is limited.

* Corresponding author.
E-mail address: pascal_haegeli@sfu.ca (P. Haegeli).

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1. Introduction

Avalanche airbags are backpacks or vests that contain one or two inflatable balloons that are manually deployed by the wearer when caught in an avalanche. Compressed gas or a battery powered fan or impeller are used to instantly inflate the stowed balloons to a total volume of about 150 L. In comparison to the standard avalanche safety devices—transceiver, probe, and shovel—that aim to accelerate the search and extrication phase of avalanche rescue, the goal of the avalanche airbag is to decrease the chance of complete burial. This is achieved through the physical process of granular convection (also known as inverse segregation or Brazil nut effect) (Gray & Ancey, 2009; Kern, Buser, Peinke, Siefert, & Vulliet, 2005), which describes the fact that in granular flows—which dry slab avalanches belong to—larger particles tend to be sorted toward the surface. While the initial concept of avalanche airbags was invented in Europe in the late 1970s, and the first commercial product became available in 1991 (Brugger et al., 2007), the broad adoption of this avalanche safety device in the winter backcountry community only occurred in the last decade.

The effectiveness of airbags is supported by various scientific studies, which include simulations (Gray & Ancey, 2009; Kern, 2000; Kern et al., 2005), field experiments where crash test dummies with inflated avalanche airbags were exposed to artificially triggered avalanches (e.g., Biskupic et al., 2012; Kern, Tschirky, & Schweizer, 2002; Meier, Harvey, & Schweizer, 2012; Tschirky & Schweizer, 1996) and statistical evaluations of accident records comparing mortality rates of avalanche victims equipped with and without avalanche airbags (e.g., Brugger et al., 2007; Brugger & Falk, 2002; Brugger, Kern, Mair, Etter, & Falk, 2003; Tschirky, Brabec, & Kern, 2000). The most recent study, a retrospective analysis of avalanche accidents involving multiple victims with at least one of them wearing an airbag by Haegeli et al. (2014), showed that inflated avalanche airbags reduced absolute mortality among victims from 22% to 11% (i.e., cut mortality by half). Hence, international organizations like the Wilderness Medical Society (Van Tilburg et al., 2017) and national avalanche safety organizations (e.g., Avalanche Canada, n. d.) recommend the use of avalanche airbags in addition to the standard avalanche safety gear of transceiver, probe, and shovel.

Despite the proven effectiveness of avalanche airbags to save lives in avalanche accidents, there is persistent concern that the positive effect of airbags could be nullified or even reversed by their unintentional negative influence on their users' risk perception and risk-taking (Haye, Boutroy, & Soulé, 2018; Wolken, Zweifel, & Tschiesner, 2014). The thought is that the added sense of security provided by the airbag would lead to riskier choices when travelling in the backcountry and thereby increase the potential for serious injury or even death. The introduction of new safety equipment is commonly accompanied by these types of concerns, which are grounded in the theory of risk homeostasis or risk compensation (Wilde, 1982, 2001). This theory posits that people are not trying to minimize their risk, but rather optimize it by maintaining an acceptable target level of risk in the context of the expected benefits and costs of both the risky behavior (e.g., skiing an untracked powder slope vs. getting caught in an avalanche) and added safety equipment (e.g., decreased chance of burial vs. cost of avalanche airbag). Hence, the added safety of an airbag might be compensated by skiing during times when the avalanche hazard is more elevated or in places where triggering is more likely.

Even though it seems obvious that people constantly adjust their behavior in response to external influences, and the theory of risk homeostasis seems plausible, the usefulness of the theory to explain the response to safety initiatives has been questioned (see, e.g., Hedlund (2000) or Thompson, Thompson, & Rivara (2001) for overview). The criticism is mainly due to the mixed results recorded by studies trying to identify risk compensation behavior and measure its impact in real-world situations. Staying close to the context of airbags, research on the unintended effects of helmet use in downhill skiing (Hagel, Pless, Goulet, Platt, & Robitaille, 2005; Hagel, Russell, Goulet, & Nettel-Aguirre, 2010; Ruedl, Abart, Ledochowski, Burtscher, & Kopp, 2012; Russell, Christie, & Hagel, 2010; Ružić & Tudor, 2011; Scott et al., 2007; Shealy, Ettlinger, & Johnson, 2005; Shealy, Johnson, & Ettlinger, 2008; Thomson & Carlson, 2015) has so far not produced consistent evidence that the introduction of ski helmets would have led to risker choices in ski areas. Similarly, mixed results have been found in research on the effect of helmet use among cyclists (e.g., Lardelli-Claret et al., 2003; Phillips, Fyhri, & Sagberg, 2011). Hedlund (2000) attributes the lack of conclusive results at least partially to the fact that measuring behavioral change pre- and post-intervention in a meaningful way is difficult. Even when observations show that behavior might have changed, its effect on accidents, injuries or fatalities are difficult to prove due to the multitude of influencing factors.

While numerous avalanche safety studies have examined the prevalence of airbag use within the backcountry community (e.g., Procter et al., 2013) and Haegeli (2012) examined the concerns and operational experiences with airbags within the Canadian professional avalanche community in detail, only few studies have explicitly tackled the risk compensation question. The possibilities for examining risk compensation in response to avalanche airbags are severely limited. Field experiments where participants' backcountry skiing behavior is examined with and without avalanche airbags are both logistically and ethically unfeasible.[1] It is also impossible to identify the effect using retrospective accident analyses as inconsistent accident reporting and the lack of large-scale backcountry use data prevents the reliable estimation of accident, injury, or mortality rates (Haegeli et al., 2014). Existing studies on the effect of airbags on risk behavior have therefore been limited to indirect methods to explore the issue. Wolken et al. (2014) conducted an online survey where participants had to assess the avalanche risk of 19 different avalanche situations and specify their willingness to ski the slope presented in the situation. The subsequent comparison between regular users of airbags and non-users revealed that while the groups did not differ in their risk perception, airbag users were significantly more likely to ski the slope. Furthermore, 18% of the sample of airbag users indicated that they had skied a slope they would not have without an airbag at least once. Also using an online survey, Margeno, Dellavedova, Monaci, and Micelli (2016) showed a positive correlation between airbag ownership and personal avalanche involvements.[2] While these types of studies offer some insight, comparisons between users and non-users of avalanche airbags are unable identify risk compensation behavior. The observed pattern might be completely explained by the fact that backcountry skiers with a higher personal risk propensity might be more likely to buy an avalanche airbag than skiers with a lower appetite for risk. To isolate the risk compensation effect properly, it is critical to examine participants' backcountry behavior or risk propensity with and without airbags (i.e., pre- and post-intervention). This approach was pursued in the survey study of Eyland and Thibeault (2016), where participants were presented with a slope-scale avalanche scenario and had to specify their acceptable threshold level of danger for skiing the slope on a scale from zero to ten under a number of slightly different circumstances. In one of the scenarios, participants had to indicate their threshold assuming they were wearing an airbag and an Avalung.[3] A comparison between the base and airbag scenarios showed that about one quarter of the survey sample (80 of 343) indicated a higher acceptable danger threshold in the scenario with the airbag (5.9 versus 4.8 on the ten-point scale). Interestingly, out

[1] See Garner et al. (2016) for an example of an experimental study on the effect of heads-up-display goggles on skiing and snowboarding speeds.

[2] However, the survey did not ask the participants to specify whether the avalanche involvement was before or after the airbag purchase.

[3] An Avalung is a breathing device that aims to prolong the survival of completely buried avalanche victims by diverting exhaled carbon dioxide-rich air away from the intake area of the oxygen-rich air for breathing (Van Tilburg et al., 2017).

Table 1
Avalanche awareness levels.

Level	Description
Unaware (1)	I generally do not think about avalanche where I ski in the backcountry.
Aware (2)	I know that avalanches can happen in some of the places I ski, but avalanche danger generally does not affect the choices I make.
Engaged 1 (3)	I sometimes worry about being caught in an avalanche. I would like to learn more about avalanche safety, but I have not had the opportunity.
Engaged 2 (4)	So far, my avalanche safety knowledge has been self-taught, but I am planning to take a formal avalanche safety course.
Non-Emerging (5)	I have taken a formal avalanche safety course, but I do not regularly apply what I learned when skiing in the backcountry.
Emerging (6)	I have taken a formal avalanche safety course and I am routinely applying these skills when skiing in the backcountry.
Practicing (7)	I have taken a formal avalanche safety course and have several years of experience in terrain selection and group management.
Guiding (8)	I am a formal backcountry group leader or work as a mountain guide.

Note: Since the survey was conducted in German, this table provides English translations of the original wording. The German text of the survey questions and response items is available from the authors upon request.

of these 80 participants, 51 had never carried and only eight always carried an airbag during their backcountry trip. While this result offers indirect evidence that risk compensation in response to airbags is a possibility, the power of the study to draw general conclusions seems limited as participants only assessed a single avalanche scenario.

The objective of the present study is to provide a more comprehensive perspective on the topic of risk compensation and avalanche airbags among backcountry and out-of-bounds skiers[4] by simultaneously examining the topic from multiple perspective. Building on the existing research, we also used an online survey to a) examine general perceptions of the effect of airbags on risk-taking among skiers, b) look at differences in attitudes towards risk-taking between users and non-users of airbags, c) examine differences in avalanche involvement rates between owners and non-owners of airbags, d) identify common reasons for or against purchasing an avalanche airbag, and e) explore changes in stated backcountry skiing terrain preferences as a function of airbag use.

2. Methods

2.1. Survey design

The online survey designed for this study consisted of several sections. In addition to general questions about participants' sociodemographic background, the survey included detailed questions to assess participants' engagement level in backcountry skiing and out-of-bounds skiing, their avalanche awareness knowledge, use of avalanche safety gear, information sources used for trip planning, and personal avalanche involvements. Participants' avalanche awareness knowledge was assessed using an 8-level ordinal scale that builds on the avalanche awareness levels identified by McCammon (2009) using the Precautionary Adoption Process Model (Table 1). This approach offers a finer assessment of avalanche awareness than just formal training levels.

To evaluate participants' backcountry risk attitudes, we used a set of nine statements related to risk-taking in backcountry skiing situations (Table 2). Participants had to indicate whether these statements applied to them on a four-level Likert scale ranging from 'Does not apply' to 'Does apply'. We chose this customized approach over the well-established Sensation Seeking Scale by Zuckerman (1994) or the abbreviated Brief Sensation Seeking Scale (BSSS) by Stephenson, Hoyle, Palmgreen, & Slater (2003) because these scales tend to be too general

[4] In this study, the term 'skiing' also refers to 'snowboarding' as we did not distinguish between the two modes of travel.

Table 2
Risk propensity question items.

Label	Description
Q1	I like to push my limits.
Q2	I like to try challenging descents (e.g., steep slopes, narrow chutes).
Q3	My motto is: The steeper the slope, the higher the enjoyment.
Q4	I am only interested in fresh tracks.
Q5	I am attracted to situations that allow me to test my skills and assess my boundaries.
Q6	Enjoying fresh powder is more important to me than properly assessing the hazard.
Q7	I am more likely to take a chance when I am with a group.
Q8	I enjoy being the best in a group setting.
Q9	Even in the presence of better alternatives, I tend to follow the decisions of my group despite feeling uneasy about it.

Note: Since the survey was conducted in German, this table provides English translations of the original wording. The German text of the survey questions and response items is available from the authors upon request.

to study risk propensities in specific activities (Thomson, Morton, Carlson, & Rupert, 2012). Furthermore, the results of Haegeli, Gunn, and Haider (2012) showed that backcountry and out-of-bounds skiers score generally quite high on the relevant sub-scales of the BSSS, which makes it unsuitable for discriminating subpopulations. Directly applying the contextual sensation seeking questionnaire for skiing and snowboarding developed by Thomson et al. (2012) was also not appropriate as not all of the included items are relevant for backcountry travel.

The survey included detailed questions about the use of avalanche safety equipment and air bag ownership. Airbag owners were presented with detailed follow-up questions that examined the importance of different purchase reasons and the length of time they have had their airbag. Survey participants who indicated that they do not own an airbag were asked to indicate the importance of different reasons for not purchasing an airbag. All survey participants were asked to indicate whether they believe that avalanche airbags increase the likelihood of risky decision-making in the backcountry on a four-level Likert scale ranging from 'I agree' to 'I disagree'.

To shed light on the effect of avalanche airbags on personal avalanche involvement rates, all participants were asked whether they had ever been personally been caught in an avalanche. If this question was answered with 'Yes', participating airbag owners were asked whether this incident occurred before or after their avalanche airbag purchase. This involvement information was then combined with participants' overall number of years of backcountry experience and the duration of their airbag ownership to calculate and contrast avalanche involvement rates of different subpopulations.

The core of the survey was a discrete choice experiment (DCE; Louviere, Hensher, & Swait, 2000), a stated preference technique that offers an attractive alternative for systematically collecting information on personal skiing preferences when direct observations are impossible. The method originated in transportation research and has been applied extensively in market research and resource economics (Adamowicz, Boxall, Williams, & Louviere, 1998), but it is now used in many areas to study consumer preferences including health care (de Bekker-Grob, Ryan, & Gerard, 2012), human resources (Lagarde & Blaauw, 2009), and recreation (Haider, 2002), just to name a few. In a DCE, respondents are presented with a series of choice sets composed of two or more alternatives that are described by a common set of attributes. Each attribute is defined by at least two distinct levels, which are varied according to a statistical experimental design. In each choice set, participants evaluate the alternatives and choose the most appealing option.

The theoretical foundation for the analysis of preference data from DCEs lies in random utility theory (RUT; McFadden, 1974), which assumes that the utility (U) gained by person n from experience i consists of an observable deterministic component (V) and an unobservable random component (ε), which is often referred to as the random error component.

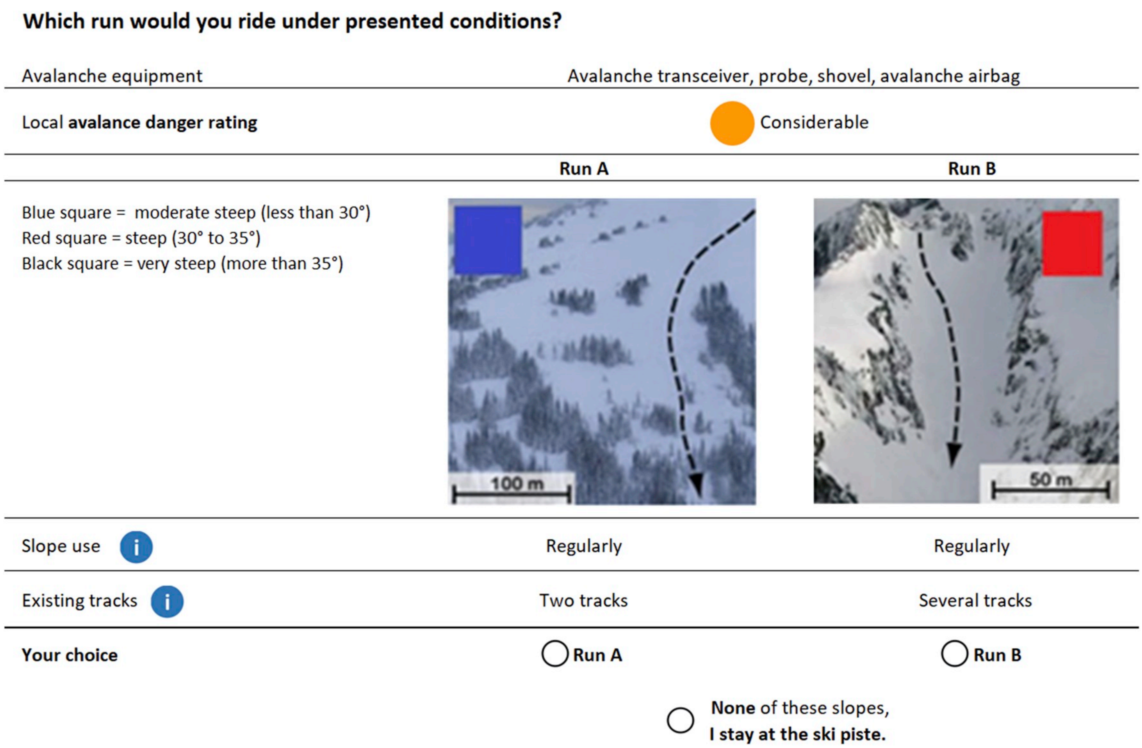

Fig. 1. Example of presented choice task.

$$U_{in} = V_{in} + \varepsilon_{in} \quad (1)$$

The fundamental assumption of choice theory is that when presented in a set of alternatives (i.e., a choice set CS_n), people act rationally and only choose the alternative that provides the highest overall utility. Despite the assumption that individual choice behavior is deterministic, the data can be analyzed stochastically in a standard multinomial logit model (MNL) for the aggregate sample population (McFadden, 1974). The MNL describes the sample population's probability of choosing alternative i in choice set CS as

$$Prob_{i|CS} = e^{V_i} \Big/ \sum_{j \in CS} e^{V_j} \quad (2)$$

The k specific characteristics of the alternatives can be incorporated into Equation (2) by expanding the observable component of the utility V_i according to

$$V_i = \beta_{0i} + \sum_{l=1}^{k} \beta_{li} f_l(X_l) \quad (3)$$

where β_{0i} represents the alternative specific constant and β_{li} are the part-worth utility (PWU) coefficients associated with the functional forms f_l of the various attributes X_l that describe the alternative. These parameters are estimated by fitting the expanded version of Equation (2) to the observed stated choice probabilities of the sample population. The resulting PWU values express the sample population's relative preference (positive coefficients) or dislike (negative coefficients) of the levels within each attribute included in the statistical design.

There are several recent studies that have used DCEs in the context of avalanche risk management. Whereas Olschewski, Bebi, Teich, Wissen Hayek, and Gret-Regamey (2012) used the method to study people's willingness to pay for avalanche protection of forests in Switzerland, the more prominent application of DCEs has been the examination of terrain preferences of winter backcountry travelers and their response to avalanche hazard conditions (Haegeli et al., 2012; Haegeli, Haider, Longland, & Beardmore, 2010; Haegeli & Strong-Cvetich, 2019). While there are justified doubts that the rational choice assumption underlying RUT accurately describes the decision mode in backcountry decision situations (e.g., Haegeli & Atkins, 2016; McCammon, 2001), the experimental setup of a DCE provides an attractive approach for examining the link between terrain preferences and environmental conditions in a controlled environment. The present study reuses a DCE that was designed by Haegeli et al. (2012) to examine risk-taking behavior among out-of-bounds skiers. Following its original application, the choice sets (Fig. 1) were set up as out-of-bounds ski situations consisting of two backcountry ski runs and staying within the ski area as a base alternative. The signal words of the European Avalanche Danger Scale (European Avalanche Warning Services, n. d.) were used to describe the avalanche conditions for a choice set, and each of the available backcountry run options was characterized by a set of terrain and ski quality attributes (Table 3).

To make the decision situations as realistic as possible, slope character, size, and steepness were presented in a single annotated photograph. We used the colors commonly used in Swiss ski areas to indicate the difficulty of ski runs (blue, red, and black squares) to indicate the run steepness. The choice task of the participants was to select the alternative they would most likely prefer to ski with their most common backcountry partners under the given avalanche conditions.

In total, each survey participant was presented with eight different choice sets with varying attribute combinations and avalanche danger ratings ranging from Low to High that followed a fractional factorial experimental design with 44 choice sets in total. To examine the effect of avalanche airbags on terrain preferences, airbag use was included as an additional binary attribute that was fully crossed with the experimental design (i.e., at the sample level, all 44 choice sets were completed both with and without airbags). The first four choice sets of all participants (one at each danger rating level) were framed as choices with familiar avalanche safety equipment (i.e., with airbag for owners and without airbags for participants who did not own an airbag[5]). In choice sets 5 to 8, participants were forced to make choices under unfamiliar conditions.

[5] Referred to as non-owners.

Table 3
Attributes and levels included in discrete choice experiment.

Attributes	Description	Attribute levels[a]
Avalanche danger rating[b]	Single word description of avalanche hazard conditions according to European avalanche danger scale (European Avalanche Warning Services, n.d.)	• Low • Moderate • Considerable • High
Slope character[c]	Type of terrain that characterizes the majority of the ski run	• Trees • Open slope • Chute
Slope steepness[c,d]	Approx. slope incline at steepest part of OB ski run where an avalanche could be triggered	• Moderate steep (blue) • Steep (red) • Very steep (black)
Slope size[c]	Approx. size of largest open slope that could produce an avalanche on the ski run	• Small (approx. 10 m) • Medium (approx. 50 m) • Large (approx. 100 m or larger)
Slope use	Frequency of common skier traffic on ski run	• Rarely • Occasionally • Regularly
Tracks	Number of tracks currently visible	• Several • Two • None

[e]Ski quality was not part of experimental design, but included in the description of the choice set to complete the characterization of the ski run.
[a] Attribute levels are listed from more to less conservative with respect to avalanche hazard.
[b] The fifth level of the European danger scale (very high) was not included in the DCE.
[c] Attributes presented combined in a single photo.
[d] Mirrors run classification scheme commonly used for indicating ski run difficulty in Swiss ski areas.

Airbag owners were told that they had to get their airbag repaired and that it was not available to them for the remaining choice sets. Participants indicating that they did not own an airbag were told that they were able to borrow one for the last four choice sets. This experimental setup (Fig. 2) offers comprehensive insight as it supports the comparison of terrain preferences between airbag owners and non-owners (Comparison 1) and properly isolates differences in terrain preferences with and without airbags within these groups (Comparisons 2 & 3). Our hypothesis is that a) more aggressive choices of non-owners with airbags relative to without, and b) more moderate terrain preferences of owners without airbags relative to with would be indicative of risk compensation behavior.

2.2. Survey deployment

We used a convenience sample for this study. Since the degree of formal organization (i.e., clubs, registries) is low among backcountry and out-of-bounds skiers, it is not possible to get comprehensive lists of potential survey participants. Instead, we recruited survey participants from Switzerland, Austria, and Germany by promoting our study on the websites of the Swiss, Austrian, and German Alpine Clubs, the Swiss Council for Accident Prevention (bfu), and Bächli Sport, a prominent provider of outdoor equipment in Switzerland. In addition, invitation emails were sent to individuals who provided their email addresses during a preliminary test of the survey. Furthermore, general invitation emails were sent to students and staff of the Zurich University of Applied Sciences (ZHAW), participants of ZHAW's 2017 CAS Outdoorsport Management program, and the personal outdoor recreation networks of the research team. The survey was open for participation from March 21 to May 1, 2017, when the final sample for the analysis was drawn. The total number of individuals visiting the survey was 703, but only the 571 (81%) indicating that they participate in backcountry or out-of-bounds skiing were presented with the full questionnaire. We did not distinguish between skiing and snowboarding.

2.3. Statistical analysis

We performed the majority of our statistical analysis in R (R Core Team, 2019). We used general descriptive statistics to describe the nature of the dataset. Comparisons between owners and non-owners of airbags were performed using Pearson's chi-squared tests, Wilcoxon rank-sum tests, and Kruskal-Wallis tests depending on whether the underlying data was nominal or ordinal, and whether the comparison was between two or more groups. Significant comparisons of multiple groups were followed with pairwise comparisons with Bonferroni corrected p-values. We considered differences with a p-value smaller than 0.050 to be significant. Differences with p-values between approximately 0.100 and 0.050 are described as marginally significant.

Since our risk propensity Likert-scale questions only included four response categories, we used the Princals method (De Leeuw & Mair, 2009; Gifi, 1990), a non-linear equivalent to classic principal component analysis that properly scales the ordinal response data prior to identifying the principal components. We conducted this analysis by employing the princals function in the Gifi package in R (Mair & De Leeuw, 2017). We subsequently used hierarchical clustering with the Ward.D2 distance measure to group survey participants according to their scores on the risk propensity principal components.

To study the effect of avalanche airbags on avalanche involvements, we compared avalanche involvement rates of different subpopulations (e.g., owners versus nonowners, owners before and after airbags purchase, risk attitude clusters) using the exact Poisson rate test. This test can be used to examine differences in incidence rates that result a series of discrete events that occur independent of each other (i.e., Poisson process). For these comparisons, the avalanche involvement rate for specific subpopulations was calculated by dividing their number of reported incidents by their total number of exposure years. These calculations involved several assumptions. First, we calculated the exposure years of each participant by taking the maximum number of their stated backcountry and out-of-bounds skiing experience years. For this, we converted the ordinal response categories for backcountry experience into numerical values using the mean number of years for each category ('1 year': 1 yr; '2–3 years': 2.5 yrs; '4–5 years': 4.5 yrs; '6–10 years': 8 years), except for the highest category ('11 + years') which we converted into 15 yrs. The exposure years of airbag owners with airbags could be estimated precisely since the survey asked them to provide the number of years they had owned their airbag numerically. The exposure years of airbag owners prior to their airbag purchase were simply calculated by subtracting their years of airbag ownership from their overall years of experience. Similarly, the number of involvements of a subpopulation was calculated by converting the categorical response

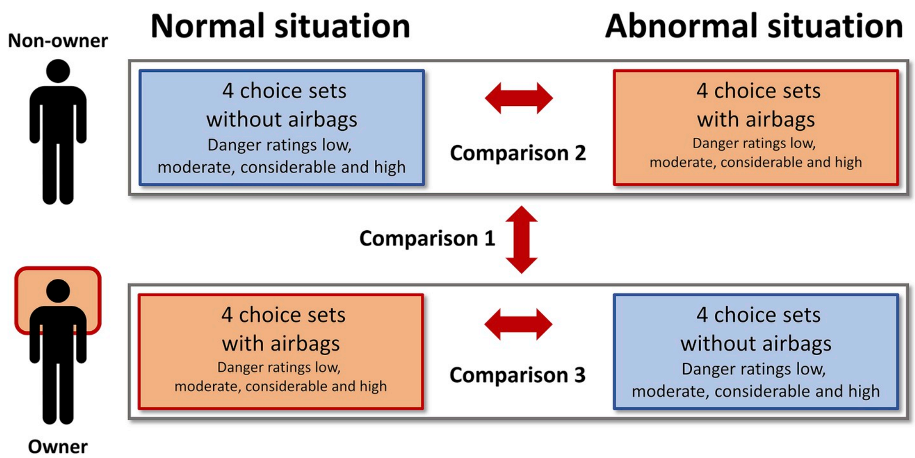

Fig. 2. Experimental setup of the DCE.

categories of the question 'Have you ever been caught in an avalanche?' into numerical values ('Yes, once': 1; 'Yes, multiple times': 2; and 'No': 0).

We performed the DCE analysis in Latent Gold Choice 5.1 (Vermunt & Magidson, 2005) and estimated four different multinomial logit models:

- A single class model with all survey participants and all eight choice sets pooled (M1).
- A two-class model with owners and non-owners of airbags and all eight choice sets pooled (M2).
- A single class model with airbag owners alone with their airbag treatment (with and without airbags) as an additional predictor interacted with all other choice set attributes (M3).
- A single class model with non-owners alone with their airbag treatment (with and without airbags) as an additional predictor interacted with all other choice set attributes (M4).

While M1 offers insights about the terrain preferences of the survey sample as a whole, the three two-class models examine our research questions illustrated in Fig. 2. Other than the model intercept, all attributes were effects coded, which means that the parameter estimates within an attribute add up to zero and the effects are relative to the average. Model selection involved the assessment of absolute model fit, model parsimony, and class interpretability. Wald statistics (Hausman & McFadden, 1984) were used to determine whether individual attributes have a significant effect on terrain preferences, and Z-scores (ratio of parameter estimates and their standard errors) were used to identify attribute levels with parameter estimates significantly different from zero.

Because of the inverse relationship between response error and PWU estimates, it is challenging to compare PWU values of models from different data sources (Louviere & Eagle, 2006; Louviere et al., 2000; Swait & Louviere, 1993). To account for this issue, the cited studies explain that the MNL equation (Equation 3) can be expanded with a scale parameter λ. While λ does not affect the PWU estimation for a single model, it allows analyses that contrast models from different sources to account for differences in error variances and ensure valid comparisons of PWU values. To address this issue in our study, we included a continuous scale factor in the two-class model M2. This approach estimates scale factors for each participant assuming that the overall distribution of the log of the scale factor is normal. Differences in the distributions between the owner and non-owners of airbags can then offer insight into differences in the magnitude of the response error between the two groups. In addition, the scale-adjusted PWU estimates make the comparisons of attribute preference differences between the two classes more rigorous. We used Wald statistics (Hausman & McFadden, 1984) to identify whether the observed differences are statistically significant.

3. Results

3.1. Characteristics of survey sample

To ensure meaningful results, we only included participants in our analysis that answered all relevant questions. Furthermore, four participants were eliminated because they chose the base alternative of not skiing in all eight choice sets of the DCE. Since every participant was presented with two choice set with low avalanche danger, we believe that these choices do not represent a meaningful response pattern for serious backcountry recreationists. The final analysis dataset consisted of 406 participants, which represented 58% of eligible individuals who started the survey.

Seventy-one percent of the sample was male (287 of 406), and while we had participants from all age categories ('15–19' to '65 and older'), the central 63% of them fell into the '25–34' and '35–44' categories. Three quarters of participants were from Switzerland (73%), 22% were from Germany, 4% from Austria and the remaining 1% (5 individuals) were from other countries. Thirty-eight percent of participants indicated that backcountry skiing is their preferred skiing activity outside of resorts, while 54% prefer skiing out-of-bounds (with and without short hikes) and 8% prefer skiing short slopes between groomed runs within resorts. Our survey participants were highly experienced in both backcountry and out-of-bounds skiing with 37% and 42% of participants having pursued these activities for more than ten years. Overall, survey participants indicated that they spend more days per season backcountry skiing than out-of-bounds skiing. While the mode for out-of-bound skiing was '3–7 trips per season', it was '8–15 trips per season' for backcountry skiing and the percentage of participants doing more than 7 trips per season was substantially higher for backcountry skiing than out-of-bounds skiing (51% versus 30%) (Wilcoxon rank-sum test: p-value < 0.001). Eighty-one percent of participants rated their skiing level as 'Advanced' or 'Expert'. Almost half of the participants indicated that they had taken an avalanche safety course and are applying these skills (46%). Another quarter of the sample indicated that they are either experienced group leaders (16%) or work as professional guides (12%). Sixteen percent of the sample reported to have personally been involved in an avalanche once and 3% reported to have had multiple involvements. Of the 77 participants reporting personal involvements, 32 (42%) indicated that they had partial burials (i.e., airway not impaired) and 5 (7%) experienced complete burials.

3.2. Risk attitudes

Our Princals analysis of the ordinal risk attitude questions revealed four components that collectively explained 70% of the observed variance. Component 1, which we labelled 'Thrill seeking', loaded heavily on all questions related to pushing one's limit and testing one's skill (Table 2: Q1, Q2, Q3, Q5). This component alone explained 32% of the observed variance. Component 2 related to 'Group dynamics' issues, such as being more likely to take a chance in a group setting and following the group even if being uneasy about it (Q7, Q9). This component accounted for another 18% of the observed variance. The last two components only loaded on a single question each. Component 3 represented the desire for 'Fresh tracks' (Q4; 11% of variance), and Component 4 stood for the attitude that the desire for powder has the potential to override proper safety precautions (Q6; 9% of variance). The question about the desire to be best in a group (Q8) did not load strongly on the first four components.

The subsequent hierarchical clustering arranged participants into three distinct groups. The first split identified the most thrill-seeking group (27% of participants), which exhibited the highest average responses in all questions except the desire for fresh tracks and skill testing questions (Q4 and Q5). Of particular interest is that this is the only group that included participants who answered the 'Powder over safety precautions' question (Q6) not with the lowest option (i.e., does not apply). The most conservative group, which included 30% of participants, had the lowest average responses in all questions. It is worth noting that everybody in this group gave the lowest rating in the 'Powder over safety precautions' question (Q6) and everybody but one person gave the lowest rating in the 'Fresh tracks' question (Q4). The responses of the final group (43% of participants) were situated in the middle between the first two groups. This group rated the thrill-seeking questions (Q1-3) almost equally as high as the thrill-seeking group but was more in line with the conservative group in the group dynamic and desire of powder questions (Q7-9). Similar to the most conservative group, all participants in this group rated the 'Powder over safety precautions' question (Q6) with the lowest rating. However, since this group rated the 'Untracked slopes' question the highest, we labelled it the conscientious seekers of fresh tracks. We did not find any differences in the proportions of the three risk attitude clusters among the participant groups that enjoy different types of backcountry trips (backcountry skiing, out-of-bounds skiing with short hikes, etc.) (Pearson's chi-squared test: p-value = 0.291).

3.3. Avalanche airbag ownership

Forty percent of survey participants (163 of 406) indicated that they owned an avalanche airbag at the time of the survey. The length airbag ownership ranged from zero years (i.e., recent purchase) to 17 years with a median length of 3 years.

Owners of avalanche airbags were significantly more likely to be males (79% versus 65%; Pearson's chi-squared test: p-value = 0.004) than non-owners, but they did not differ significantly in age (Wilcoxon rank-sum test: p-value = 0.324). The proportion of airbag owners was significantly higher among committed out-of-bounds skiers who enjoy doing short hikes to reach their run (60%) and significantly lower among participants who only ski short slopes between controlled runs (16%) (Pearson's chi-squared test: p-value < 0.001). Of the participants who preferred out-of-bounds skiing without hikes, 43% were airbag owners. Of the participants who favored backcountry skiing, 30% were airbag owners. Overall, the sample of airbag owners was more experienced and committed to the sport. They reported more years of experience in out-of-bounds skiing (Wilcoxon rank-sum test: p-value < 0.001) and more frequent backcountry and out-of-bounds skiing per season (Wilcoxon rank-sum test: p-value = 0.018 and < 0.001). Airbag owners also assessed their skiing skills significantly higher (Wilcoxon rank-sum test: p-value < 0.001) and indicated significantly higher levels of avalanche awareness (Wilcoxon rank-sum test: p-value < 0.001). However, we did not detect a significant difference in the avalanche involvement rates without airbags (Non-owners: 44 involvements in 2390 experience years; Owners: 20 involvements in 1224 experience years; Exact Poisson test: p-value = 0.694) nor among the backcountry risk attitude group membership (Pearson's chi-squared test: p-value = 0.725).

3.4. Avalanche airbag attitude and use

Overall, survey participants indicated that they believe that avalanche airbags have the potential to result in at least some risk compensation behavior. Only 14% of our sample chose 'Do not agree' when asked whether airbags increase the risk propensity of backcountry and out-of-bounds skiers. While we did not find significant differences in the agreement among the backcountry risk attitude groups (Kruskal-Wallis test: p-value = 0.473), airbag owners agreed significantly less with the idea of airbags causing risk compensation (Wilcoxon rank-sum test: p-value = 0.006) and 18% completely disagreed with the statement.

We found clear differences in the importance ratings that airbag owners assigned to different reasons for purchasing their airbag (Kruskal-Wallis test: p-value < 0.001). The two most important reasons were "I am generally interested in increasing my safety" (72% very important and 19% important) and "Statistics show higher chance of survival" (65% very important and 32% important). The reasons "Recommended by other person" (11% very important and 16% important) and "I don't trust my partners to dig me out" (9% very important and 15% important) were next with equal importance ratings. Even though only 4% indicated that "Because my partners have an airbag" was very important, 21% indicated that it was important. Less than 10% of participants rated "So that I can go by myself", "To ski steeper slopes", and "I would like to expose myself to higher hazard" as important or very important. However, airbag users belonging to the thrill-seeking cluster rated the reason "I would like to expose myself to higher hazard" significantly more important that the other clusters (Pairwise Wilcoxon rank-sum test: corrected p-values < 0.001) and "To ski steeper slopes" significantly more important than the conscientious seekers of fresh tracks cluster (Pairwise Wilcoxon rank-sum test: corrected p-value = 0.001). The conservative cluster rated the importance of favorable survival statistics significantly more important than the thrill-seekers (Pairwise Wilcoxon rank-sum test: corrected p-value = 0.018).

Among the participants who did not own an airbag (243 of 406), two reasons for not purchasing an airbag emerged as being significantly more important that others (Kruskal-Wallis test: p-value < 0.001). The most important was cost with 28% and 35% of participants rating this reason as very important and important respectively. The second most important reason was the additional weight of airbags with 19% very important and 24% important ratings. All other possible reasons (no useful benefit for my safety, would increase my risk-taking, does not decrease chance of burial, and do not travel in avalanche terrain) were assessed roughly equally with almost 50% of the ratings at the lowest importance level.

3.5. Avalanche involvement rates among airbag owners

Overall, 160 airbag owners reported both the length of their overall backcountry experience and their airbag ownership. These 160 reported 37 personal avalanche involvements in total, 20 (54%) of these involvements were prior to their airbag purchase, while 17 (46%) were after. Combined with the respective number of years of exposure, the resulting annual avalanche involvement rates of 0.016 without airbags and 0.029 with airbags are just not significantly different from each other (Table 4; Exact Poisson test: p-value = 0.103). Examining the avalanche involvement rates for the different risk attitude groups revealed that while there was no difference in the rates with and without

Table 4
Avalanche involvement rates of airbag owners before and after airbag purchase and results of exact Poisson rate test.

Group	N	Prior to airbag purchase			Post airbag purchase			p-value
		Counts of involvements	Years of exposure	Involvement rate per year	Counts of involvements	Years of exposure	Involvement rate	
Most conservative	47	3	337	0.009	3	161	0.018	0.396
Conscientious powder seekers	73	15	574	0.026	7	254	0.028	1.000
Most thrill seeking	40	2	313	0.006	6	133	0.045	0.011
All airbag owners	160	20	1224	0.016	16	548	0.029	0.103

Table 5
Parameter estimates for DCE – Model (M1): All respondents, and Model (M2): Owners vs. non-owners of airbags (scale-adjusted PWU estimates).

Attribute and attr. levels	M1 - All respondents (406)			P-values [d]	M2 - Owners (163)			Non-owners (243)			P-values [d]	
	PWU	SE	Sign. [c]	Attribute	PWU	SE	Sign. [c]	PWU	SE	Sign. [c]	Attribute	Group-diff.
Avalanche danger rating				<0.001							<0.001	0.970
Low	2.067	0.130	***		2.107	0.244	***	2.174	0.190	***		
Moderate	0.926	0.094	***		0.957	0.165	***	0.873	0.125	***		
Considerable	−0.537	0.080	***		−0.589	0.132	***	−0.547	0.107	***		
High	−2.456	0.083	***		−2.475	0.153	***	−2.500	0.125	***		
Slope character				<0.001							<0.001	0.110
Trees	0.205	0.040	***		0.119	0.063		0.248	0.056	***		
Open slope	−0.027	0.050			−0.096	0.075		0.007	0.065			
Chute	−0.177	0.056	**		−0.022	0.086		−0.255	0.076	***		
Slope steepness				<0.001							<0.001	0.049
Moderately steep	0.963	0.051	***		0.860	0.082	***	1.080	0.075	***		
Steep	−0.100	0.044	*		−0.129	0.066		−0.071	0.060			
Very steep	−0.863	0.054	***		−0.731	0.084	***	−1.008	0.079	***		
Slope size				<0.001							<0.001	0.110
Small	−0.185	0.056	***		−0.146	0.083	*	−0.277	0.079	**		
Medium	−0.032	0.037			−0.110	0.055	*	0.047	0.051			
Large	0.217	0.050	***		0.256	0.078	***	−0.230	0.069	**		
Slope use				0.002							0.032	0.930
Rarely	0.146	0.042	**		0.127	0.065	*	0.144	0.056	***		
Occasionally	−0.052	0.041			−0.025	0.063		−0.043	0.056			
Regularly	−0.094	0.052			−0.102	0.081		−0.100	0.071			
I stay within resort [a]	−0.293	0.058	***	<0.001	−0.436	0.102	***	−0.186	0.080	*	<0.001	0.057
Pseudo-R^2 [b]	0.261				0.227			0.291				

[a] Model constant.
[b] Model performance.
[c] Significance level of PWU: * = 0.05; ** = 0.01; *** = 0.001.
[d] P-value statistics - attribute: Wald; group-difference: Wald (=).

airbags for the most conservative and conscientious powder seeker groups (Exact Poisson test: p-values = 0.396 and 1.000), the involvement rate among members of the most thrill-seeking group increased significantly from 0.006 involvement per year of exposure prior to their airbag purchase to 0.045 after purchase (Exact Poisson test: p-value = 0.011).

3.6. Terrain preferences

After exploring different configurations for all of the models, the final versions of our models included the main effects of all attributes except ‘Tracks’, which did not emerge as significant in any of the examined models. The PWU estimates of the overall model (M1) that included all respondents (n = 406) with eight choice sets each exhibited the expected patterns (Table 5). The context variable ‘Danger rating’ emerged as a highly influential attribute (i.e., biggest range of PWU estimates) with lower avalanche hazard levels being preferred over higher ones. Among the slope parameters, participants generally preferred treed runs over open slopes and chutes, liked moderately steep slopes more than steep and very steep slopes, and tended to choose large slopes over medium and small slopes. In addition, they preferred runs that were rarely skied over runs that were occasionally or regularly skied. The negative PWU for the base alternative ‘I stay within resort’ indicates that participants had a strong base preference for choosing one of the two available ski runs. The pseudo-R^2 of M1 was 0.27, which represents a decent model fit according to Hensher, Rose, and Greene (2015).

Model M2 contrasts the general terrain preferences of airbag owners with non-owners. An analysis of the distributions of the continuous scale factor revealed that there are no differences in the response errors between the two classes (mean log-scale factor: 0.0006 (owner) vs. 0.0005 (non-owner); Student t-test: p-value = 1.000). Overall, the two classes exhibited similar patterns for all of the included attributes (Table 5). However, the scale-adjusted PWU values revealed several significant differences in their preferences. Relative to airbag owners, non-owners exhibited stronger preferences regarding ‘Slope steepness’, i.e., stronger preference of moderately steep slopes and stronger dislike of very steep slopes (Wald statistic: p-value = 0.049). Furthermore, the non-owner PWU of the base alternative was also less negative (−0.186 versus −0.436; Wald statistic: p-value = 0.057) indicating a slightly weaker tendency towards choosing one of the out-of-bounds slopes versus staying within the resort. Even though not significant at the 0.1 level, the preference in ‘Slope character’ and ‘Slope size’ are also worth mentioning. While owners were indifferent regarding slope character, non-owners showed a relative preference for treed slopes and a relative dislike for chutes (Wald statistic: p-value = 0.110). Furthermore, while owners exhibited a preference for large slopes, non-owners preferred medium slopes (Wald statistic: p-value = 0.110). All other PWU

Table 6
Parameter estimates for DCE – Model (M3): Owners with airbag interaction.

Attribute and attribute levels	Main effects				Interaction effects with airbag			
	PWU	SE	Sign.[c]	p-value[d]	PWU	SE	Sign.[c]	*p*-values[d]
Avalanche danger rating				<0.001				0.915
Low	2.055	0.305	***		−0.079	0.419		
Moderate	1.053	0.222	***		−0.113	0.308		
Considerable	−0.568	0.184	***		0.008	0.254		
High	−2.541	0.191	***		0.184	0.264		
Slope character				0.032				0.131
Trees	0.155	0.085			−0.025	0.124		
Open slope	−0.245	0.111	*		0.310	0.155	*	
Chute	0.090	0.125			−0.286	0.175		
Slope steepness				<0.001				
Moderately steep	0.956	0.115	***		−0.174	0.159		0.554
Steep	−0.170	0.093			0.058	0.135		
Very steep	−0.786	0.117	***		0.115	0.162		
Slope size				0.029				0.457
Small	−0.222	0.119			0.211	0.169		
Medium	−0.068	0.080			−0.072	0.112		
Large	0.290	0.109	**		−0.139	0.157		
Slope use				0.035				0.152
Rarely	0.244	0.096	*		−0.223	0.131		
Occasionally	−0.015	0.087			−0.074	0.125		
Regularly	−0.229	0.112	*		0.296	0.161		
I stay within resort [a]	−0.414	0.134	**	0.002	−0.013	0.185		0.094
Pseudo-R^2 [b]	0.230							

[a] Model constant.
[b] Model performance.
[c] Significance level of PWU: * = 0.05; ** = 0.01; *** = 0.001.
[d] p-value statistics - attribute: Wald.

Table 7
Parameter estimates for DCE – Model (M4): Non-owners with airbag interaction.

Attribute and attribute levels	Main effects				Interaction effects with airbag[d]			
	PWU	SE	Sign.[c]	p-value[d]	PWU	SE	Sign.[c]	p-value[d]
Avalanche danger rating				<0.001				0.870
Low	2.034	0.230	***		0.179	0.335		
Moderate	1.009	0.175	***		−0.186	0.241		
Considerable	−0.517	0.148	***		−0.045	0.208		
High	−2.527	0.153	***		0.051	0.218		
Slope character				<0.001				0.038
Trees	0.393	0.077	***		−0.262	0.108	*	
Open slope	0.045	0.095			−0.035	0.131		
Chute	−0.438	0.110	***		0.297	0.151	*	
Slope steepness				<0.001				0.840
Moderately steep	1.030	0.095	***		0.062	0.137		
Steep	−0.026	0.088			−0.060	0.118		
Very steep	−1.004	0.106	***		−0.002	0.149		
Slope size				0.16				0.860
Small	−0.188	0.112			−0.081	0.151		
Medium	0.011	0.073			0.018	0.099		
Large	0.177	0.094			0.063	0.133		
Slope use				0.030				0.066
Rarely	0.132	0.079			0.044	0.110		
Occasionally	−0.182	0.077	*		0.237	0.110	**	
Regularly	0.051	0.097			−0.281	0.138	**	
I stay within resort [a]	−0.215	0.106		0.043	0.044	0.150		0.773
Pseudo-R^2 [b]	0.295							

[a] Model constant.
[b] Model performance.
[c] Significance level of PWU: * = 0.05; ** = 0.01; *** = 0.001.
[d] p-value statistics - attribute: Wald.

estimates did not differ significantly between owners and non-owners of airbags. The pseudo-R^2 for the two classes in this model were 0.263 (airbag owners) and 0.311 (non-owners).

Model M3 examines differences in the terrain preferences of airbag owners with and without airbags by estimating main effects for without airbags and interaction effects that describe the effect of airbag in terrain preferences (Table 6). The observed preferences described by the main effects are generally consistent with the patterns observed for the owner class in M2. While the interaction effects did not reveal any significant effects of airbags at the attribute level, the parameter estimate for ‘Open slope’ was significant at the 0.05 level. This provides some evidence that owners might have a slight preference for open slopes when wearing their airbags. The pseudo-R^2 value for this model (0.230) indicates a fit quality that is comparable to the owner model in M2.

Finally, Model M4 examined differences in terrain preferences of non-owners with and without airbags (Table 7). Like M3, the observed preferences are generally consistent with the patterns observed for the non-owner class in M2, with the exception that slope size did not emerge as a significant attribute in M4. However, different from M3, we observed significant airbag interaction effects, which indicate that providing non-owners with an airbag changed their terrain preferences. While the main effect indicates that non-owners generally prefer more conservative terrain (i.e., trees over chutes), the interaction effect shows the opposite pattern, which means that their preference for treed slopes and dislike for chutes disappeared in the scenarios with airbags (Wald statistic: p-value = 0.038). A similar pattern can be observed in the parameter estimates for the 'Slope use 'attribute. While the main effect PWU shows a dislike of occasionally skied slopes relative to regularly skied slopes, the interaction effect reverses this pattern (Wald statistic: p-value = 0.066). There is no effect on the preference of rarely skied slopes. With a pseudo-R^2 value of 0.295, the model for non-owners has the highest overall fit of all models included in this study.

4. Discussion

The results of the present study provide insight into the topic of risk compensation and avalanche airbags among backcountry and out-of-bounds skiers from a variety of perspectives. Overall, survey participants generally agreed that avalanche airbags have the potential to result in risk compensation behavior. Even among our sample of airbag owners, 82% of participants stated that airbags can lead to increased risk-taking.

Our comparison of non-owners and owners of avalanche airbags revealed several important differences. In general, our sample of airbags owners was older, more experienced, pursued their activity of choice more frequently, and reported higher levels of skiing skills and avalanche awareness. Airbag ownership was also substantially more common among committed out-of-bounds skiers who enjoy short hikes to get to their ski runs. While this study did not explicitly examine participants' general motivations for skiing uncontrolled backcountry slopes, other studies (e.g., Haegeli et al., 2010; Haegeli et al., 2012; Zweifel, Techel, & Björk, 2012) have noted that out-of-bounds skiers tend to be motivated more by challenging skiing than traditional backcountry skiers. These observations suggest that airbags are generally purchased by committed skiers who are aware that they are exposing themselves to higher levels of risk. The results of our DCE confirm this conclusion as the PWU estimates of M2 indicate that non-owners of airbags generally have more conservative terrain preferences (i.e., stronger preferences for moderately steep slopes versus very steep slopes, dislike for large slopes, preference for treed slopes, weaker base preference for skiing out-of-bounds). These results support the idea that owners of airbags are substantially different from non-owners and might pursue backcountry skiing in a way that inherently exposes them to higher levels of avalanche risk. Hence, Wolken et al. (2014)'s result showing that owners of airbags were more likely to choose skiing a slope in their scenarios and the fact that Margeno et al. (2016)'s sample of airbag owners reported higher life-long avalanche involvement rates can likely be explained by the identified differences between owners and non-owners of airbags.

While this comparison between owners and non-owners cannot be used to directly conclude that airbags lead to risk compensation, understanding the underlying motivations for pursuing backcountry skiing can still offer important indirect evidence for assessing the potential for risk compensation. Following the reasoning of Hedlund (2000), backcountry and out-of-bounds skiers interested in challenging skiing might be more susceptible to risk compensation because their objective is inherently more in conflict with maximizing safety than the objective of skiers primarily interested in enjoying nature. Hence, the analysis of our survey participants provides some evidence that the segment of backcountry and out-of-bounds skiers who have purchased avalanche airbags might have a higher propensity for risk compensation behavior simply due to their personal motivations, preferences, and interests. However, our analysis of avalanche involvement rates did not reveal significant differences among the different risk attitude groups.

Non-owners' stated reasons for not purchasing an airbag offer additional insight into whether airbags might lead to risk compensation behavior. Among our participants, the purchase cost of avalanche airbags and the weight penalty were clearly the biggest deterrents for purchasing an airbag, which confirms the results of previous studies (e.g., Haegeli, 2012). Both of these deterrents fall into Hedlund (2000)'s category of obvious negative impacts that make users very aware of the presence of the additional safety device. Hedlund (2000) argues that the likelihood for risk compensation is much larger for safety devices that are clearly visible than invisible ones (e.g., penetration resistant windshields). While avalanche transceivers might quickly fade from users' awareness because they only need to be turned on once in the morning, this is clearly not the case for airbags, where the weight penalty, the leg loop, and the prominent trigger handle constantly affects users both physically and mentally. It seems reasonable to conclude that users of airbags might be tempted to increase their exposure to avalanche hazard to compensate for the constant inconvenience.

In addition to these indirect lines of evidence, the results of the DCE analysis also indicate that avalanche airbags have the potential to lead to risk compensation. Our comparison of stated terrain preferences with and without airbags show that owners might make slightly more conservative choices when their airbags are taken away, whereas non-owners tend to make more aggressive choices when airbags are given to them. However, it is difficult to determine how exactly these observed preference patterns in these hypothetical decision situations transfer into the real world. While DCEs have provided useful general insight into terrain preferences among winter backcountry users (e.g., Haegeli et al., 2010; Haegeli et al., 2012; Haegeli & Strong-Cvetich, 2019), responses to online scenarios are inherently limited as they cannot fully represent the physical and emotional complexities of true backcountry decision situations. Risk compensation behavior is mainly an emotional response that depends on situational cues, and it is incredibly difficult to fully represent the situation in a survey setting. DCEs employing virtual reality (e.g., Patterson, Darbani, Rezaei, Zacharias, & Yazdizadeh, 2017) might offer new avenues for making these experiments emotionally more realistic. Given the fact that the hypothetical decision situations used in our study were less emotionally loaded, we suspect that the observed risk compensation patterns might likely be more pronounced in the real world.

Another important aspect is that risk compensation behavior in the real world can only occur if individuals are actually able to change their behavior (Hedlund, 2000). Recreational backcountry travelers essentially have complete freedom and full control over their behavior. Hence, they can freely adjust their behavior in response to added safety devices. This is different from other activities (e.g., safety equipment in professional sports, helmet for cycling) or professional backcountry guiding where established rules, laws, and operating procedures prevent individuals from increasing their risk exposure.

Complementing the indirect evidence presented, our analysis of avalanche involvement rates among airbag owners before and after their purchase revealed some indication that risk compensation is occurring. While the difference in involvement rates with and without airbags for all owners was just slightly over the 0.1 significance level, a significant increase emerged for the thrill-seeking group, whose rates rose from 0.006 to 0.045 involvements per exposure year after purchase. While these calculations included several simplifications, it is important to note that the effect of the main assumption—capping the length of backcountry experience at 15 years—has the potential to produce estimates of exposure years without airbags that are too small and therefore involvement rates that are too high. This means that the risk compensation signal might even be more pronounced with more accurate exposure data.

While this study provides considerable evidence that risk compensation among airbag users is likely, it is important to note that the risk compensation response might also change over time. Hedlund (2000) hypothesizes that once one becomes accustomed to a new safety device one might slide back into previous patterns. The results of Ružić and Tudor (2011) that occasional wearers of ski helmets expose themselves to more risk than regular users and non-users confirms this possibility. Similarly, Garner, Haegeli, and Haider (2016) showed that the effect of heads-up-display goggles on skiing speeds fades relatively quickly. Hence, it seems reasonable to assume that the desire to increase risk-taking after purchasing an airbag also has the potential to disappear again over time. The fact that our DCE analysis found stronger evidence for potential risk compensation behavior among non-owners (M4) than owners (M3) could be interpreted as support for this hypothesis.

The findings of the present study should be considered in light of the inherent limitations of survey research with a convenient sample. Several existing survey studies in avalanche safety (e.g., Furman, Shooter, & Schumann, 2010; Haegeli et al., 2012; Haegeli & Strong-Cvetich, 2019; Winkler & Techel, 2014) have highlighted that the types of recruitment channels we used for the present study tend to result in survey samples that are biased towards committed recreationists with an existing interest in avalanche safety. Furthermore, the context of a safety survey may cause participants to provide more conservative answers due to social compliance effects. Because of these reasons, extrapolating our results to the general population of backcountry users should only be done with great care. We encourage researchers to conduct similar studies in other regions and with other participant samples to provide deeper insight into the topic of risk compensation among winter backcountry users.

5. Conclusions

While avalanche airbags can reduce mortality in avalanche involvements (Haegeli et al., 2014), their potential to trigger risk compensation behavior calls into question their effectiveness for increasing avalanche safety overall. The goal of the present study was to provide a comprehensive perspective on the topic of avalanche airbags and risk compensation by examining it from a variety of perspectives.

Using an online survey, we questioned a sample of 406 backcountry and out-of-bounds skiers including both airbag owners and non-owners about their backcountry experience, risk attitudes, risk management practices, and airbag use. The results of our analysis provide both indirect and direct evidence that risk compensation in response to avalanche airbags is likely in at least some segments of the backcountry and out-of-bounds skiing population. Participants' personal perception of the effect of avalanche airbags on skiing behavior, their motivations for partaking in the activity, and their responses regarding reasons for or against airbag purchases indicate that airbags align well with the four conditions promoting risk compensation outlined by Hedlund (2000): a) they are blatantly obvious; b) they negatively affect one's backcountry experience due to their constant need for management (i.e., securely fastening, arming and disarming, charging, etc.) and the weight penalty; c) users interested in skiing challenging slopes have a reason to change their behavior to satisfy their desire; and d) recreationists have complete freedom to change their behavior. While this does not mean that every new airbag owner will increase their exposure to avalanche hazard, it clearly highlights that airbags have the potential to result in risk compensation behavior. This is confirmed by the fact that the majority of our survey participants—91% among non-owners and 82% among owners—stated that they believe that airbags can lead to at least some degree of risk compensation. The results of our DCE and avalanche involvement rate analyses further strengthen this conclusion by providing additional evidence that is more closely linked to actual behavior.

Given the conclusion that risk compensation is likely, the important next question is whether this unintended effect of airbags is a strong argument against their use. Winter backcountry recreation is a personal choice that is associated with inherent risks that are impossible to completely eliminate. While the implied goal of the avalanche safety community is to increase safety overall, avalanche awareness courses and avalanche safety devices primarily enable recreationists to pursue backcountry activities they otherwise could not in an informed and skilled manner. Avalanche Canada's tagline of their former mountain snowmobile avalanche safety campaign "Go farther, experience more, be safe. Become avalanche trained," clearly illustrates this reality. However, to allow recreationists to make informed choices and ensure they do not overcompensate, it is critical to properly inform them about the benefits, limitations, and potential risks of avalanche airbags. The great majority (96%) of airbag owners in our survey stated that 'Statistics that show higher chance of survival' were important or very important for their purchase. While the study of Haegeli et al. (2014) offers some insight on how the benefit of avalanche airbags is quickly nullified by being involved in larger avalanches, more detailed studies are required to better understand these interactions. We therefore reiterate the recommendation of Haegeli et al. (2014) to encourage national avalanche safety agencies, international bodies, and airbag manufacturers to develop standardized data collection protocols, and reporting guidelines to support continued research on the effectiveness of avalanche safety devices. Furthermore, we recommend the topic of risk compensation to be included in the curricula of avalanche safety courses and discussed in the support documentation and user manuals of avalanche airbags to ensure that users are aware of this unintended potential side effect.

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