END USER INTERPRETATION OF THE AVALANCHE DANGER SCALE: A SCOTTISH STUDY

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ABSTRACT: In this study, we investigate Scottish end users' understanding and interpretation of the five point European Avalanche Danger Scale. Our main findings are, first, that many end users report to draw on detailed avalanche information including the avalanche problem information in their planning. Second, only seven in ten end users are aware that there are five danger levels. Third, end users' risk perception of the danger scale, which we elicited using numerical probability judgements about each danger level, increases mostly linearly—results that cohere well with recent findings by Morgan et al. (2023) who used a different response format and a North American user group. Lastly, we report the results of an exploratory analysis whether individual characteristics of end users (such as their outdoor sport experience, age, gender, avalanche education), predict the individuals' interpretation of the danger level. We find these characteristics have little explanatory power, which suggests that avalanche education needs to take a broad and inclusive approach to improve the intended understanding of the avalanche danger scale. We finish our discussion by contextualising the main findings.

Keywords: avalanche danger scale, probability, risk perception, avalanche risk communication

1. INTRODUCTION

An indispensable tool for winter sports participants to make informed decisions about the avalanche danger are *avalanche forecasts* issued by local, regional or national avalanche warning services. In order to provide accessible and relevant information, avalanche warning services issue avalanche forecasts using the so-called EAWS information pyramid. Most prominent is the most general information: the EAWS standardised colour-coded five point ordinal *avalanche danger scale* that ranges from *1 – low* (green), *2 – moderate* (yellow), *3 – considerable* (orange), *4 – high* (red), to *5 – very high* (black) avalanche danger (EAWS, 2023).

The avalanche danger level is a function of three main determinants: snowpack stability (which is inversely related to the probability of an avalanche triggering), the frequency distribution of snowpack stability (i.e. how widespread trigger points with the lowest snowpack stability rating are within the forecasted region), and the expected avalanche size for a given unit (area and time). The resulting avalanche danger level applies to a wider region covering a range of at least 50km^2 (EAWS, 2023).

For risk communication purposes, each EAWS avalanche danger level has a colour-coded icon and a descriptor that specifies the avalanche conditions for that level in relation to "snowpack stability" and the "likelihood of triggering" an avalanche (Figure 1). The latter descriptor includes important information about the expected *trigger likelihood* presented using verbal probabilities ("possible", "likely"), about the expected *trigger size*, (i.e. whether an individual or a group is generally required to trigger an avalanche), and about the expected *avalanche size and type* (human triggered vs. natural). One important aspect of the avalanche danger scale as a risk communication tool is that scientists and forecasters generally interpret the expected avalanche danger to increase *exponentially* (Schweizer et al., 2020). Indeed, some avalanche warning services, such as the Swiss avalanche services (SLF) explicitly highlight the exponential nature in their official guidance noting that: "the probability of an avalanche triggering increases sharply as the danger level rises." (SLF 2022; see Figure 2).

There has been a recent increase in research on *end user* understanding and interpretation of the avalanche danger levels and the avalanche forecasts more generally. Engeset et al. (2018) provided the first large scale study of end users, identifying how different modes of communication affect their level of comprehension of the more detailed information. Using a mixed methods approach St. Clair et al. (2021) have identified different user groups of the avalanche forecast who each draw on different levels of specificity in their avalanche risk assessment, while Fisher et al. (2021) showed how the

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European Avalanche Danger Scale (2018/19)				
	Danger level	**Icon**	**Snowpack stability**	**Likelihood of triggering**
5	very high		The snowpack is poorly bonded and largely unstable in general.	Numerous very large and often extremely large natural avalanches can be expected, even in moderately steep terrain*.
4	high		The snowpack is poorly bonded on most steep slopes*.	Triggering is likely, even from low additional loads**, on many steep slopes*. In some cases, numerous large and often very large natural avalanches can be expected.
3	considerable		The snowpack is moderately to poorly bonded on many steep slopes*.	Triggering is possible, even from low additional loads**, particularly on the indicated steep slopes*. In certain situations some large, and in isolated cases very large natural avalanches are possible.
2	moderate		The snowpack is only moderately well bonded on some steep slopes*; otherwise well bonded in general.	Triggering is possible, primarily from high additional loads**, particularly on the indicated steep slopes*. Very large natural avalanches are unlikely.
1	low		The snowpack is well bonded and stable in general.	Triggering is generally possible only from high additional loads** in isolated areas of very steep, extreme terrain*. Only small and medium natural avalanches are possible.

Figure 1: The EAWS Avalanche Danger Scale as used by all European Avalanche Warning Services, including snowpack stability and likelihood of triggering descriptors. (*) indicated steep slopes are slopes steeper than 30 degrees, moderately steep terrain are slopes shallower than 30 degrees; (**) low additional loads denotes an individual skier, while high additional loads indicates two or more skiers; natural avalanches occur without human influence.

type of presentation of the more specialised aspect and altitude information in avalanche forecasts has an effect on their interpretability by the end user. A recent study by Terum et al. (2023) has identified the effect of increasing and decreasing historical trends in danger ratings on end users' perception of the current danger rating level. Finally, the in-depth and extensive study by Morgan et al. (2023) on end user interpretation of the avalanche danger scale found that roughly 65% of North American end users increased their numerical interpretation of the North American avalanche danger level in a linear fashion.

In this article, we present results of our survey of Scottish end users of the Scottish Avalanche Information Service's avalanche forecasts. We investigate end users' use and knowledge of the avalanche danger scale and test how an increase in danger levels affects end user interpretation of the probability of triggering an avalanche. The latter is elicited using numerical probability judgements. Adopting a probabilistic perspective has received renewed interest for avalanche risk communication for at least three reasons. First, the EAWS has introduced the use of numerical estimates at least for the determinant of frequency of snowpack stability in the EAWS Matrix to ensure a more consistent avalanche forecasting approach amongst its member states. Second, a numerical approach has the potential to provide objectively testable verification procedures for the avalanche danger levels and allows us to easily compare user perception using the established probability scale. Thirdly, using the numerical approach helps us to understand how individuals perceive and interpret an increase in the avalanche danger level, at least with respect to one of its dimension, in a fine grained way. This, in turn, allows us to assess directly whether end users perceive the increase in the probability of triggering to be a "sharp" one or not.

As such, this short contribution draws on our general summary report (Ebert and Comerford, 2022) and on our in depth academic contribution (Ebert

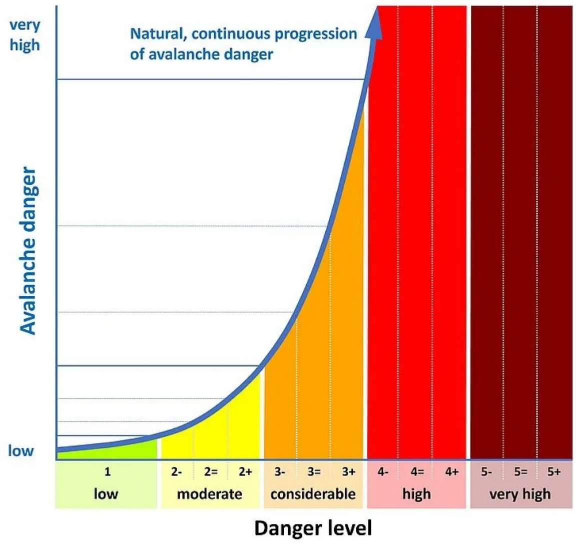

Figure 2: The exponential and continuous increase of the avalanche danger in relation to the reported avalanche danger levels as presented by the Swiss Forecasting Service SLF (2022). Note that sub-levels are currently only in use in Switzerland and have not been adopted within the EAWS more widely.

et al., 2024). Please consult in particular the latter article, for additional insights and more detailed results and discussion.

2. END USER KNOWLEDGE AND INTERPRETATION OF THE AVALANCHE DANGER SCALE

2.1 Survey participants

The survey was presented as a collaboration between researchers at the University of Stirling and the Scottish Avalanche Information Service (SAIS). Participants were recruited with the help of the SAIS community through their website, word-of-mouth, advertisements (UKclimbing.com, walkhighlands.com), and Facebook groups such as BritishBackcountry. The survey received Ethics approval from the University of Stirling. Data and R-code can be downloaded here: https://osf.io/8ekvx/?view_only=38b9914de2d94c1fbfd362de585d358f

The survey was designed using Qualtrics software and open for a six week period from March 2021 to April 2021. A total of 1193 respondents took part of which 702 completed the survey and of these 678 reported prior acquaintance with the avalanche forecasts for planning winter activities. Participants were not forced to answer each question which resulted in variation in sample size which is reported below. The median age category was 45–54 with substantial variation (per-age-category counts were as follows 18–24: 36, 25–34: 110, 35–44: 144, 45–54: 161, 55–64: 147, 65–74: 66, 75–84: 7, prefer not to say: 1). Of those who responded to the gender question, 543 respondents identified as male, and 117 as female, while 1 selected neither category and 9 declined to say. We also asked participants what their highest level of formal education attained was, which skewed heavily towards higher education (Postgraduate degree: 293, undergraduate degree: 330, A-level/GCSE/high school: 93, never finished school: 3, prefer not to say: 18).

When asked about their experience in winter sports, the modal experience level was more than 20 years (activities include: skiing, snowboarding, skitouring, winter climbing, winter walking, respondents could provide primary and secondary winter activities), with 535 respondents having more than 5 years experience. For primary sport, we had the following responses 1-2 winters: 38, 3-5 winters: 95, 6-10 winters: 106, 11-20 winters: 166, more than 20 winters : 266. In their secondary activity, 1-2 winters: 63, 3-5 winters: 89, 6-10 winters: 112, 11-20 winters: 127, more than 20 winters: 222.

2.2 Experimental Questions and Design

We asked survey participants basic questions about their use and knowledge of the avalanche danger scale. First, we asked users what information from the avalanche forecast users typically draw on when they plan a winter sports activity. Possible responses were structured along the information pyramid and included no use of any information (option 1), the avalanche danger level (option 2), the avalanche danger level and location-specific information (altitude and aspect) of the avalanche danger (option 3), or all of the above and information about the sepcific avalanche problems (option 4). Second, we asked end users to specify how many avalanche danger levels there are and offered them the choice between '3', '4', '5', '6', 'I'm unsure', 'prefer not to say'. Following on from this, we asked respondents to name the avalanche danger levels in a free text response format.

We then explored end users risk perception by soliciting numerical estimates of the likelihood of triggering an avalanche for a given avalanche danger level so to identify how their perceived avalanche risk increases with increasing avalanche danger level. We adopted three different response formats to which respondents were randomly assigned. We used a percentage chance frame and two frequency frames with different denominators: x-many avalanche per-100 *slopes* versus x-many avalanches per 100-*days*. While we found some differences due to the response format (for details, see Ebert et al. 2024), we have decided to merge the three response formats in this contribution. Respondents were asked to provide a point-valued (as opposed to interval-valued) *best estimate* of the likelihood of an avalanche on a given slope for each avalanche danger level in ascending order from *low* to *very high* using a sliding numerical scale from 0-100. Using the frequency format as an example, we solicited responses using the following vignette:

Frequency slope

> Imagine a large steep snow slope in an area that is rated to have one of the five hazard levels. Out of a 100 slopes with the same characteristics and hazard level, how many slopes will avalanche if a person crosses it? Please provide your best estimate for each hazard level.

2.3 Statistical Methods

To assess how well participants' responses match the assumed exponential ("sharp") increase in the probability of triggering an avalanche with increasing danger level, we used two methods. First, to assess the "average users" response, we fitted a generalized additive mixed model (GAMM; Wood 2017) to the 0–100 responses (rescaled to 0–1, so we could model using a binomial response), with danger level and a random effect of participant ID as predictors. To assess whether the relationship was exponential we fitted a model where the danger level was a linear effect, plus a smooth (spline) effect for danger level. This allowed us to determine how much the responses deviated from a linear fit, and accommodates any shape of response. We used a random effect for each individual, which would account for each participant having an overall higher or lower response. Using the individual gave maximum flexibility in this situation as it will encompass variation from other variables (e.g., from gender, age, etc). We do not need to interpret this effect (it is effectively a nuisance variable in this analysis), so for predictions used in plots we set its coefficient to be zero.

Second, given the possibility of averaging effects in that some users' convex response patterns (being suggestive of an exponential interpretation) and others' concave response pattern might cancel each other out, we also investigated individual responses directly. A minimal condition for exponentiality is that the increase in numerical value of the probability of avalanche triggering per danger level is itself increasing. More simply put: end users who associate say a 5% probability to *low* and 10% probability to *moderate*, can only exhibit an exponential increase if their response to the next danger level *considerable* is 16 or greater (so: the increase is greater between moderate and considerable, than between low and moderate). See Table 1 for the formal characterisation of our condition for exponentiality. In our discussion, we will call a response that meets condition 1-3 as presented in Table 1, a *limited exponential* response. We call a response that meets all four conditions, an *exponential* response.

In order to investigate to what extent different characteristics of the respondents affects whether they

Condition 1:	$UR(2) - UR(1) > 0$
Condition 2:	$UR(3) - UR(2) > UR(2) - UR(1)$
Condition 3:	$UR(4) - UR(3) > UR(3) - UR(2)$
Condition 4:	$UR(5) - UR(4) > UR(4) - UR(3)$

Table 1: **Minimal condition for exponentiality**: UR(x) stands for the individual user response at a given danger level x. Users whose response patterns fulfils Condition 1-4 offer what we call an *exponential* response, while users that fulfil Condition 1-3 will be regarded as offering a *limited exponential* response (limited to danger levels 1-4.)

tend to provide expontential response, we used a generalized additive model (GAM) with an ordered categorical response (Hastie et al., 1989). This allowed for us to use the three exponentiality categories defined above, in order, as the response. The model can then be used to investigate if, say, increasing avalanche training will lead to an increase in the exponentaility of the users' responses. The use of a GAM allowed for factor, linear and smooth variables to be included in the model, giving a lot of flexibility (Wood, 2017). The smoothers will also "fall back" to linear terms if there is not enough data to support a more complex shape.

We used the following predictor variables in our regression: age (smooth; mean in category; dropping 7 "prefer not to say"), gender (factor; male, female; dropping a further 17 non-binary/"prefer not to say" responses), outdoor winter experience (smooth; number of winters 1-2, 3-5, 6-10, 11-20, 20+), avalanche education (smooth; categories "No formal training", "Avalanche Awareness session", "Avalanche Awareness day", "Avalanche course with field day (2-3 days)", "Professional or advanced avalanche course (4-5 days)"; dropping 2 non-respondents), time since last avalanche training (smooth; 0-2 years ago, 3-5 years ago, 6 or more years ago; dropping 1 non-respondent). Dropping those samples with non-responses for the ratings, we were left with 196 evaluations of the exponentiality of users' responses.

Using smoothers to model the ordered factor variables in the model gave greater flexibility to account for non-linear changes between the categories (e.g., sudden jumps, changes in slope between categories etc). We began by including all variables in the model and used backwards selection to remove terms which were not significantly different than zero (where the p-value was < 0.01).

2.4 Results

6 out of 10 survey respondents reported to be using advanced avalanche information in their planning which includes the altitude and aspect information, as well as information about the specific avalanche problems (Figure 3). Only 1 out of 10 respondents reported to only use the avalanche danger scale in

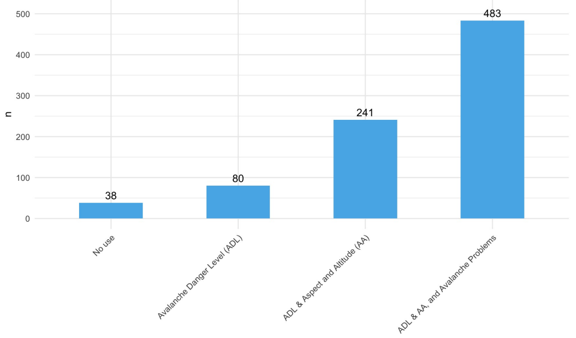

Figure 3: Avalanche information that end users report to use from the avalanche forecasts in their planning (reported as counts).

preparation for winter sport activity. We found that 7 out of 10 respondents correctly stated that there are five distinct avalanche danger level, with most incorrect responses either reporting there to be four danger levels, or being "unsure" (see Figure 4).

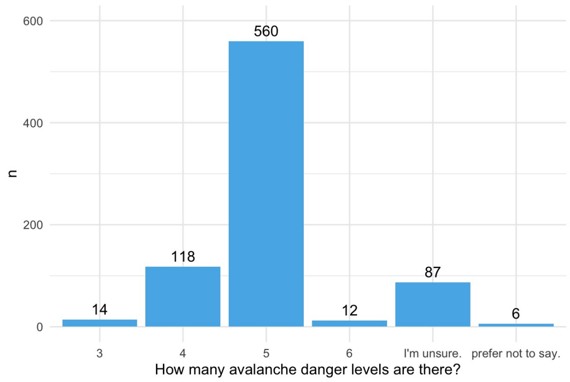

Figure 4: Number of respondents for each possible response to the question of how many avalanche danger levels there are.

There were a wide range of responses to name the different avalanche danger levels. To see the diversity of responses, see our word cloud (Figure 5).
With respect to assessing how the probability of an avalanche triggering changes with increasing danger level, we received in total 1596 danger level evaluations (responses from 320 individuals across 5 questions, with one non-complete evaluation). We discarded one response (giving a total of 1595) where the response was 0 for a non-*low* danger level (0 was the default value on the scale); as such, we assumed this was an error from the respondent. The resulting model showed that the relationship was almost linear. The linear term was significant ($p < 1 \times 10^{-16}$). The smooth term was significantly different from zero ($p = 1.4 \times 10^{-6}$). As the smooth terms are extremely flexible, we would expect them to fit to any deviation from linearity, the term has an effective degrees of freedom of 2.67 (a linear term has 1 degree of freedom), so this is a very small deviation from the linearity in the model (which might be expected given the amount of variation in the

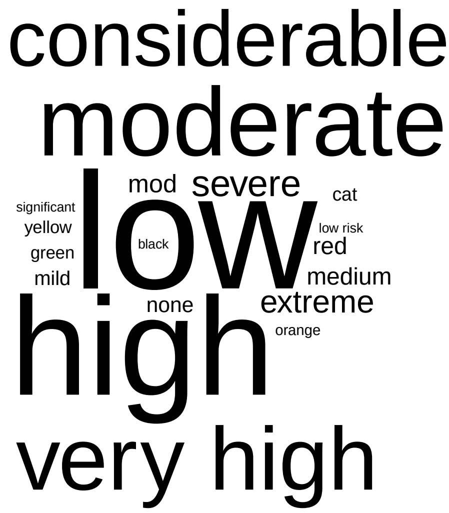

Figure 5: Wordcloud showing the responses to the question asking respondants to name the avalanche danger levels. Words with fewer than 5 responses are not shown.

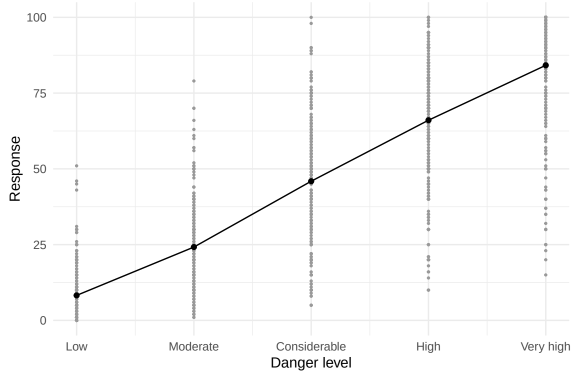

Figure 6: Relationship between danger level and the end user responses. Grey points show the data, black points show the model fit with the lines joining showing the implied relationship.

data, see Figure 6). It appears that the average end user interpretation, merging all three response formats, is not strictly linear, but it is certainly not distinctively exponential nor does it represent a "sharp" increase, as is shown in Figure 6. Note, that this small effect vanishes, when we control for the different response formats that end users received, for details see Ebert et al. (2024). Looking at the individual responses (see Figure 7) and our condition of exponentiality as outlined in Table (1), we find that 98.75% respondents meet Condition 1, 70.62% me Condition 2, then there is a significant drop and only 25.31% meet Condition 3, while just 10.63% meet Condition 4 and thus offer an exponential response pattern.
The model to identify whether some groups of end users are more likely to exhibit an exponential response did not find any predictors that were significantly different from zero at the 0.01 level. Inter-

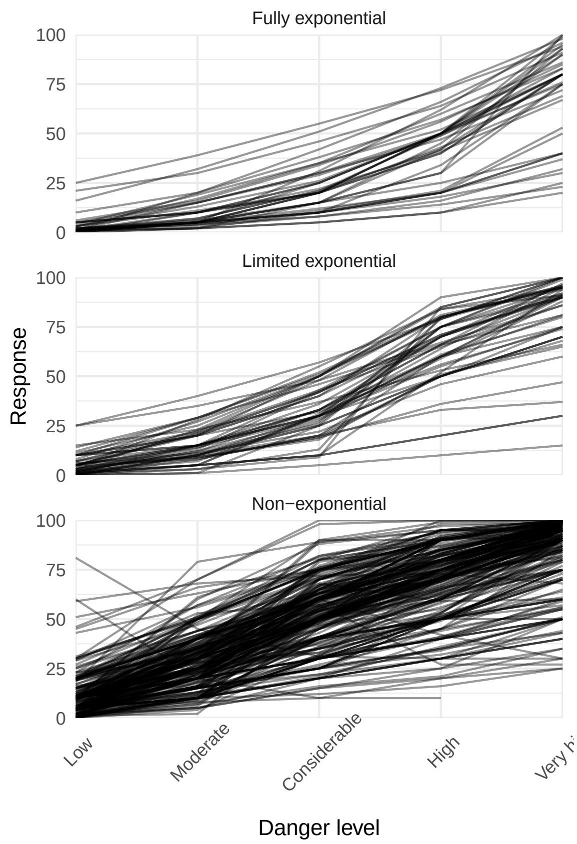

Figure 7: End user responses estimating the probability of an avalanche at each avalanche danger level. Each line is the response from one user. Rows show responses that are exponential (conditions 1-4 met), limited exponential (conditions 1-3 met) and non-exponential (remaining). We included all responses in this figure, i.e. also those that were excluded from the other analyses due to missing data, non-completion of the survey, etc.

mediate models inspected during model selection had extremely low explanatory power (deviance explained of 6% maximum). Note that there were in total 144 non-exponential responses, 35 limited exponential and 17 fully exponential, and the small number of responses at the limited and fully exponential levels may well have made the modelling more difficult. As such, these limited results suggest further research and more data is needed to increase confidence in these findings, see Section 3..

3. DISCUSSION

Most end users report to use advanced avalanche information in their planning. However, how well they understand the information and whether they incorporate it correctly into their own decision-making are questions this survey did not investigate. Still, given there is a clear desire by our survey participants to access this information, we believe that avalanche forecasting service should ensure that avalanche danger levels, altitude and aspect, as well as avalanche problem information are easily identifiable on their website.

We were surprised to learn that only 7 out of 10 survey respondents correctly reported that there were five avalanche danger levels. But looking at Figure 4 more closely, we can see that most respondents who offered the “wrong” response either thought that there are only four avalanche danger levels or reported to be unsure about the correct number of avalanche danger levels. The fact that since its inception more than 25 years ago the Scottish Avalanche Information Service has only issued one of the first four danger levels, might help to explain why some respondents believe that there are only four such levels, or why they are unsure.

We are not sure how best to address this knowledge gap or “confusion”. The fact that the highest danger level is *de facto* not used in some countries such as Scotland, and hardly ever used by those forecasting services who have issued it, should raise some questions about its relevance as a risk communication tool, at least in relation to winter sports participants (for further discussion, see (Morgan et al., 2023, 4.3) for an overview). Another challenge for the highest level in the context of forecasting is that it is very difficult to forecast reliably (Techel and Schweizer, 2017; Statham et al., 2018). Finally, given that the highest level is, from an end user perspective often practically irrelevant and might lead to anchoring effects which could threaten to undermine the correct interpretation of the lower ratings (Eyland, 2018), is something that deserves further scrutiny from a behavioural science research perspective.

We found clear evidence that end users do not regard the probability of triggering to increase “sharply” with rising avalanche danger levels. Rather, end users’ response format is fitted fairly well using a linear regression. Looking at our criterion of exponentiality, we can say that only roughly (25%) offer wa limited exponential response, while 75% of respondents offer a more linear or even concave response pattern. Hence, according to end users, the probability of triggering does not seem to increase “sharply”. Now while we focus on end user estimates to only one dimension of the avalanche danger scale (i.e. the probability of triggering an avalanche), any inference as to how the avalanche danger levels *per se* is interpreted by end users needs a further assumption. However, assuming that only very few respondents will regard the increase in probability of avalanche triggering to be linear yet the avalanche danger scale to still increase exponentially due to the the other two dimensions, our study provides new and cohering evidence to existing work by Morgan et al. (2023) that showed more directly, using a North American sample, that the avalanche danger scale *per se* is interpreted to increase linearly by 65% of their respondents.

The reasons why it is important to correct a linear interpretation is that it will lead to an underestimation of the *relative* increase in avalanche danger with increasing avalanche danger levels, which could, in turn, lead to a serious underestimation of the incurred personal risk of the higher danger levels *considerable* and *high* by winter sports participants (for further discussion, see Morgan et al. 2023; Ebert et al. 2024).
Lastly, in a finding important for avalanche education, we could not identify any clear end user characteristic that would predict that certain groups of end users are more likely or less likely to give an exponential response. Surprisingly, the time since participating in formal avalanche training also seems to have no effect on whether the end user provides an exponential response. The latter finding suggests that the topic of the exponential nature of the avalanche danger scale has not made it into avalanche education courses in Scotland. The former more general finding suggests that, for the purposes of improving avalanche education, the identified knowledge gap in end user understanding of the avalanche danger scale, applies quite generally and there are no specific user groups that are more at risk of a misinterpretation and ought to be targeted. Even the most experienced and well-educated users seem not to appreciate that the probability of triggering an avalanche increases sharply with increasing avalanche danger level. However, as we noted in section 2.4, given the sample size our confidence in these findings is low (though a similar finding is also reported in Morgan et al. 2023). We hope that this study encourages others to pursue further research (and collect more openly-accessible data) on how individuals interpret the EAWS avalanche danger scale and what effect it has on their decision-making in avalanche terrain.

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