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Colours and maps for communicating natural hazards to users with and without colour vision deficiency

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ABSTRACT

Natural hazards are often communicated visually using colours and maps. However, users' ability to read and understand these products may be hampered by e.g., colour vision deficiency, potentially rendering the products less effective or even counter effective. To study these effects, we conducted two web-based surveys and analysed how to improve visual communication of avalanches, floods, landslides, and dangerous weather hazards. In survey 1 (n = 79), we tested four traffic light colour palettes, three map legends, and three map patterns used for communicating danger levels on the Norwegian website Varsom.no, to improve accessibility for individuals with and without colour vision deficiency (CVD). In survey 2 (n = 960), we tested four versions of traffic light colour palettes on a larger and international population. Survey 2 also tested six versions of Avalanche terrain exposure scale (ATES) maps on individuals with and without CVD varying in nationality, avalanche education and familiarity with ATES. Results suggest that the colours, legends, and maps used on Varsom should be improved, and that danger levels are best communicated with the colour palette used by Meteoalarm.info – in combination with symbols to help users with CVD. This study found that the colour scheme used for ski run difficulty in Europe was efficient for use with ATES maps for participants with and without CVD and is recommended as a worldwide standard for ATES. Further studies and testing of users' understanding are recommended to improve clarity of danger level maps and to improve visualization of ATES classes 0 and 1 on maps. Our studies show the hidden potential for efficient and inclusive communication of natural hazards and highlights the importance of including the needs of CVD users in standardisation efforts.

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1. Introduction

1.1. Background and motivation

Humans are visual animals. Our colour vision serves us to rapidly assess, e.g., danger or food quality. Using colours can facilitate communication across language barriers. Warm colours like reds and yellows are more efficient at communicating than cold colours like blues and greens [1], noting that this would depend on what is being communicated. For example, warm colours like red, orange, yellow might be more efficient at communicating danger than cool colours, but less efficient at communicating safety (often portrayed using green) than cool colours [2]. notes the importance and well documented use of colour for visualizing risk, but also other cartographic design features, such as animation, interactivity, and depth cues, to represent risk and uncertainty and to influence risk perception. Signalling of natural hazards should be universally understood and efficient. Effective colour codes should be visual distinct, learnable and stand for unique entities [3]. Usage of colour schemes like the traffic light scheme, which is commonly used for signalling danger levels [4], relies on normal trichromatic vision. However, colour vision deficiency (CVD) is prevalent in about 8% of the global male population and 0.4% of the global female population [5], and as many as 20–30% of adults with abnormal colour vision do not know they have CVD [6]. Distinguishing red–green is the most common problem followed by blue–yellow. CVD prevalence vary regionally from about 4% in Africa and Asia [7,8] to 10–11% in Scandinavia [9]. It is imperative to use colour schemes that are efficient for individuals with CVD and full colour vision (FCV). Misuse of colours is a common mistake with the consequence of distorting the intended message or making data unreadable [10,11].

The degree of colour disablement varies from one person to another (e.g. Ref. [6], which makes it challenging to create colour designs for persons with CVD. It is interesting to note also that colour vision often becomes progressively worse at a faster rate than visual acuity as a person ages. This is important to keep in mind when designing interfaces for an aging population. Thus, there is a growing need for improvement in colour vision standards and their acceptance internationally [12]. In Norway, as in many other countries, this is addressed in a law of universal design [13] based on success criteria in Web Content Accessibility Guidelines (WCAG) 2.0. Accordingly, a universal design for warnings, which will be in line with WCAG 2.0 [14] and national laws of universal design are desirable. Universal design can be described as the design of products and environments to be useable by all people, to the greatest extent possible, without the need for adaptation or specialized design. Important principles are equitable use, flexibility in use, simplicity, and intuitiveness – all being relevant to colour coding of natural hazard warnings. The WCAG criteria should be considered in the design and communication processes to ensure that all users can access the information that is conveyed by colour differences, that is, using colours where each colour has a meaning assigned to it.

Research has been conducted on how to design messages for hazard control [15–17]; Wogalter, 2006; [18], frequently used to inform people at risk about the hazard and to promote safe behaviour [19]. The main motivation for our study is to assess how colours and maps are used to communicate natural hazards to users with and without colour vision deficiency. This matters from the perspective of citizen inclusion, participation, and democracy, as users may be excluded from public services, awareness, and debate through shortcomings in visual communication. Even more so it matters from a perspective of safety, as users may not be aware of, and appropriately act on, intended messaging from warning service providers – or in a worst case even interpret safe as dangerous and dangerous as safe with fatal consequences. There are different standards related to how colours are used for hazards (e.g., the European Avalanche Warning Service, www.avalanches.org) or ISO 22324 [20] stating that red, yellow and green (and the spectrum in between in terms of hue) should be used to express the status of a hazard, while black, purple, blue and grey should be used to give supplementary information about the hazard.

In this paper we address the visual communication issues with a focus on natural hazards which vary in time and space (such as the avalanche danger level) or purely in space (such as maps using the Avalanche Terrain Exposure Scale, ATES [21], to communicate how different terrain is exposed to avalanches). This study is a follow up of a previous study on the efficacy of communication of avalanche warnings [22].

1.2. Objectives

The overarching aim of this research was to ensure more inclusive warning services, including efficient communication for users with and without colour vision deficiency. We focused on the use of colours, legends, and maps to provide a better knowledge base for future improvements. Web-based surveys were used, as the studied products are web-based, and they are an efficient way to collect data from many users. We designed our study based on the following research questions:

1. On danger level colour palettes: Could the colours in the traffic light palette be adjusted to be more accessible for individuals with colour vision deficiency, and at the same time work well for individuals with full colour vision?
2. On danger level legends: Could the legend (numbers and colours which explains the level of danger) be improved for people with colour vision deficiency, and at the same time work equally well for individuals with full colour vision?
3. On danger level maps: What could be done to make the maps more useable to all users?
4. On the Avalanche terrain exposure scale: What could be done in terms of colours and patterns on maps to help make the scale communicate better to all users?

To ensure efficient visual communication of natural hazards, we conducted two surveys assessing alternatives to existing schemes. In survey 1, we assessed different versions of the traffic light scheme used for signalling danger levels. We distributed this survey in Norwegian for FCV and for CVD, and in English for CVD. Survey 2 was in English with a larger international distribution to primarily investigate different versions of the ATES maps. This latter survey also included a follow up, to test more versions of the traffic light scheme on a much larger and more diverse population of users.

1.3. Outline

Background, aims and objectives are presented in section 1. Section 2 describes methods and results from survey 1, which developed and tested colour palettes, legends, and maps for communicating danger level information to colour vision deficient users. Section 3 describes methods and results from survey 2, which was in two parts (a follow-up investigation of colours based on the findings from survey 1 and an investigation of how to communicate the ATES on maps) and tested on a much larger and varied population than that of survey 1. Section 4 discusses our results, practical implications, and limitations. Section 5 provides recommendations, and section 6 draws conclusions. The annex includes colour codes used and selected feedback from respondents of survey 2.

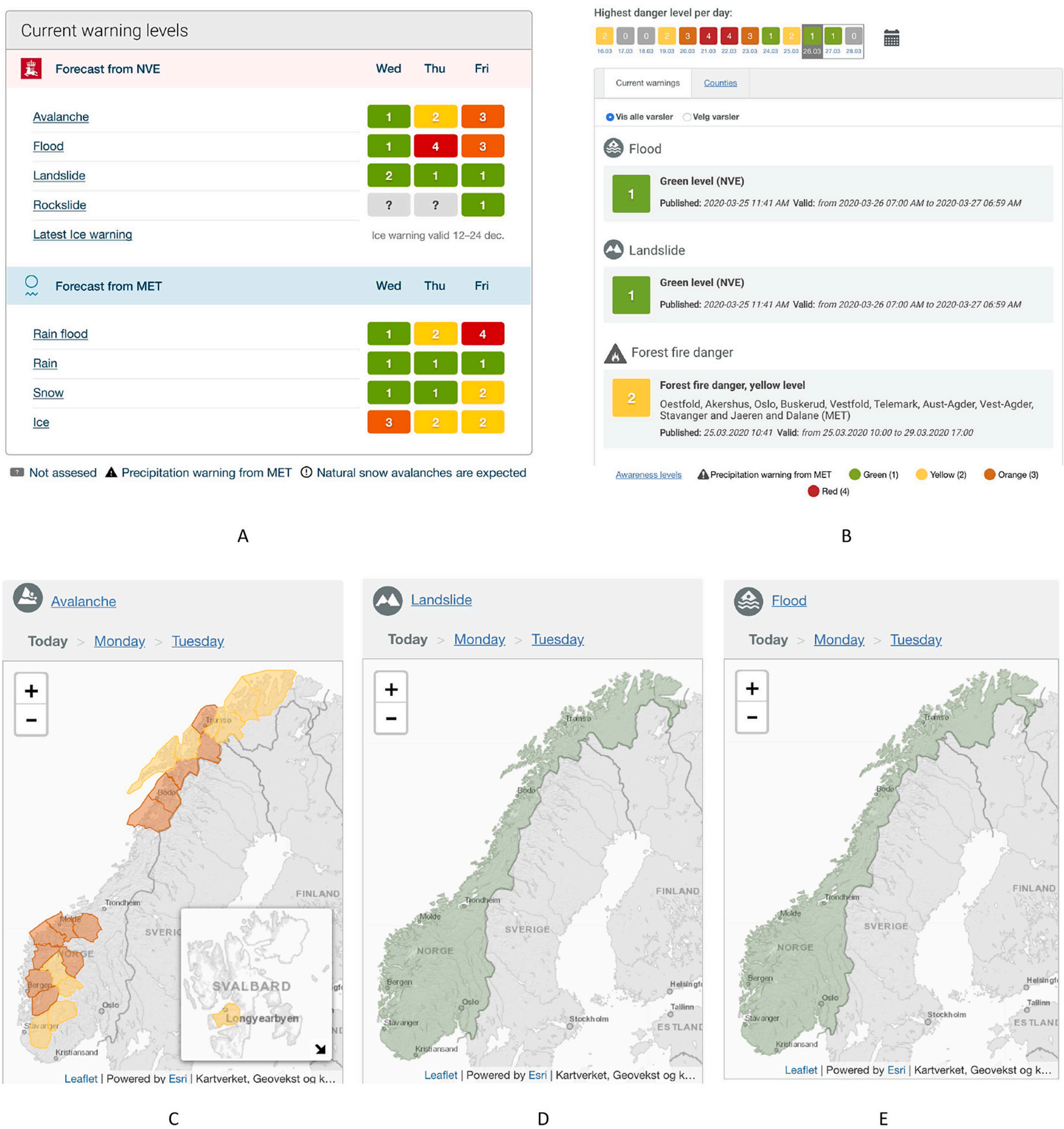


Fig. 1. Varsom.no has two different views of the current warning levels: A and B: Examples of how warnings are presented using tables with numbers and colours. C, D and E: Examples of how the current warning levels are displayed on maps using colour only.

2. Survey 1: Adopting danger level communication for colour vision deficiency: colour palette, legend, and map

In survey 1, we developed and tested four different versions of colour palettes, three different versions of legends, and three versions of map representations to communicate danger level information. The warnings on flood, landslides, rockslides, avalanches, and dangerous weather in Norway are to be found at the website Varsom.no. The warnings are labelled with colours built on the principle of the traffic light, to express the different levels of caution or danger. Varsom.no provides two different main views of current warning levels, where the first view has an overview table of all warnings provided in two layouts (Fig. 1A and B) and the second view has maps showing the different colour coded levels (Fig. 1C and D).

2.1. Colour palettes, legends, and maps

The colour system initially developed for Varsom.no was based on the traffic light colours and developed by a graphics designer without specific attention to other systems apart from making the colours pleasing and separable when viewed on the internet in standard browser software.

As Fig. 1A and B shows, Varsom.no uses the traffic light palette annotated by numbers at an ordinal scale matching the colours, and thereby fulfils the WCAG requirements of universal design as there is textual (numerical) information available that works for everyone. Varsom also displays warnings on maps (Fig. 1C and D), without supplementary support using annotation, numbers etc., which is less in line with universal design principles. As Fig. 2 illustrates, green is easily confused with orange and even red among persons with deutan CVD, which is the most common type of CVD (green cone pigment absorption spectrum shifted to longer wavelengths of light, confusing white with green, and reds, yellows, and greens) [6]. Adding a legend may confuse rather than explain the levels for people with CVD. Thus, the legend would not meet the principles in universal design [45], that it should be flexible in use, simple and intuitive. We therefore aimed to design the legend to promote intuition and simplicity to all users, including a person with CVD. Asking both CVD and FCV users, ensured a user centred design approach where the product suits the user rather than the user suits the product [23].

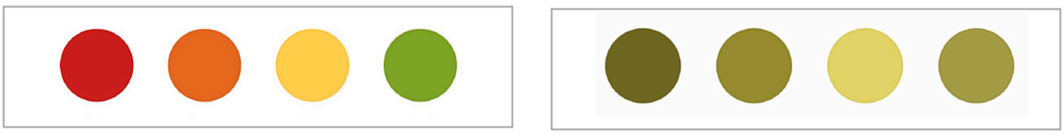
Maps are a well-used and powerful tool for communicating danger in different parts of a country. The user may zoom in and out on the map and locate themselves or another point of interest in the map, and the map will show the geographical location of the different danger levels or hazards. As the danger level is shown with a colour, the denotative task of accessing this information is challenging for persons having problems to discriminate the colours as it may also be for people with full colour vision if the colours are not intuitive or have poor readability or separability.

In both survey 1 and 2, we investigated if the colours of the traffic light palette could be adjusted to be more accessible for individuals with CVD, by keeping the convention of traffic light but tweaking the current colours. This was undertaken to assess if there is a better variant of the currently used colour palette, which also works for persons with FCV. We developed three new colour palettes. The aim was to increase readability for individuals with CVD and at the same time not derail too far away from the original colours and weaken the strength of the traffic light symbolism. We tested the colour palettes against each other and against the palette used on Varsom.no as of 2020. Secondly, we tested three different versions of the legend on both persons with CVD and persons with FCV. Thirdly, we tested different ways of communicating danger levels on maps by adding different types of symbols to the maps. The latter was motivated by WCAG 2.2 [24], which calls for conveying colour-coded information through another visual means to ensure that users who cannot see colour can still perceive the information.

2.2. Methods

2.2.1. Participants and recruitment

Norwegian participants with CVD were recruited through the webpages of the Norwegian Water Resources and Energy Directorate (NVE). Furthermore, the Norwegian Association for the Blind (NAB) announced the survey on their Facebook page. The foreign CVD participants were recruited through a CVD space at Reddit Public Access Network (Reddit.com). The participants for the full colour vision survey were recruited through Facebook, family, and friends. Those invited were asked to share and invite others to the survey. The survey was open 7–14 April 2020 and attracted 79 participants, 55 with FCV and 24 participants identified as CVD (12 non-Norwegian). Age and gender data were not collected. The participants were informed that the objective of the survey was to gain new knowledge and more insight on how to improve the communication of natural hazards for people with colour vision deficiency. The survey was available in Norwegian and English and implemented in Google forms. Data collection was fully anonymous. The recruitment process was open and used several distribution channels. We do not think our sample is biases towards reading hazard maps and warnings as nearly all English respondents reported that they had no prior knowledge of Varsom.no. Furthermore, a large portion of NVE staff that may have disseminate information about this survey is also not working with hazards but rather energy, licencing, and management, and we recruited through external sources including Reddit and NAB.



A B

Fig. 2. A: Colour palette used by Varsom. B: Simulation of how this colour palette may appear to a person with deutan CVD.

2.2.2. *Four versions of the colour palette*

As nearly all (95%) colour vision deficiencies involve abnormal perception of red and green colours [43], the colours between red and green should be avoided. A bluish green is recommended for substituting a regular green and a magenta for replacing the classic red colour [25]. The new versions of the warning palettes are based on these principles combined with adjustments in lightness and contrasts, to somehow make each palette distinct. These are common tools in strategies to help persons with colour vision deficiency [26].

Discrimination and information loss can be approximated using a CVD simulation. To design new versions of the maps, legends, and colour palettes we primarily used the software simulator Color Oracle [44]. Color Oracle simulates three pure forms of colour vision impairment [27]: Deuteranopia, protanopia and tritanopia. The designers of the software highlight that the milder forms of CVD, such as partial or shifted sensitivity on colours, are more common than the extreme forms, which are characterized by a complete absence of one type of cones. However, they conclude that if a colour scheme works for extreme colour vision impairment, it is also legible to persons with less impairment [5]. We also checked the new information design using the Color Universal Design simulator in Photoshop [28] and the simulator Sim Daltonism [29]. The three new colour palettes, the colour palette as per 2020, and the tested legends and maps are all detailed in the Appendix.

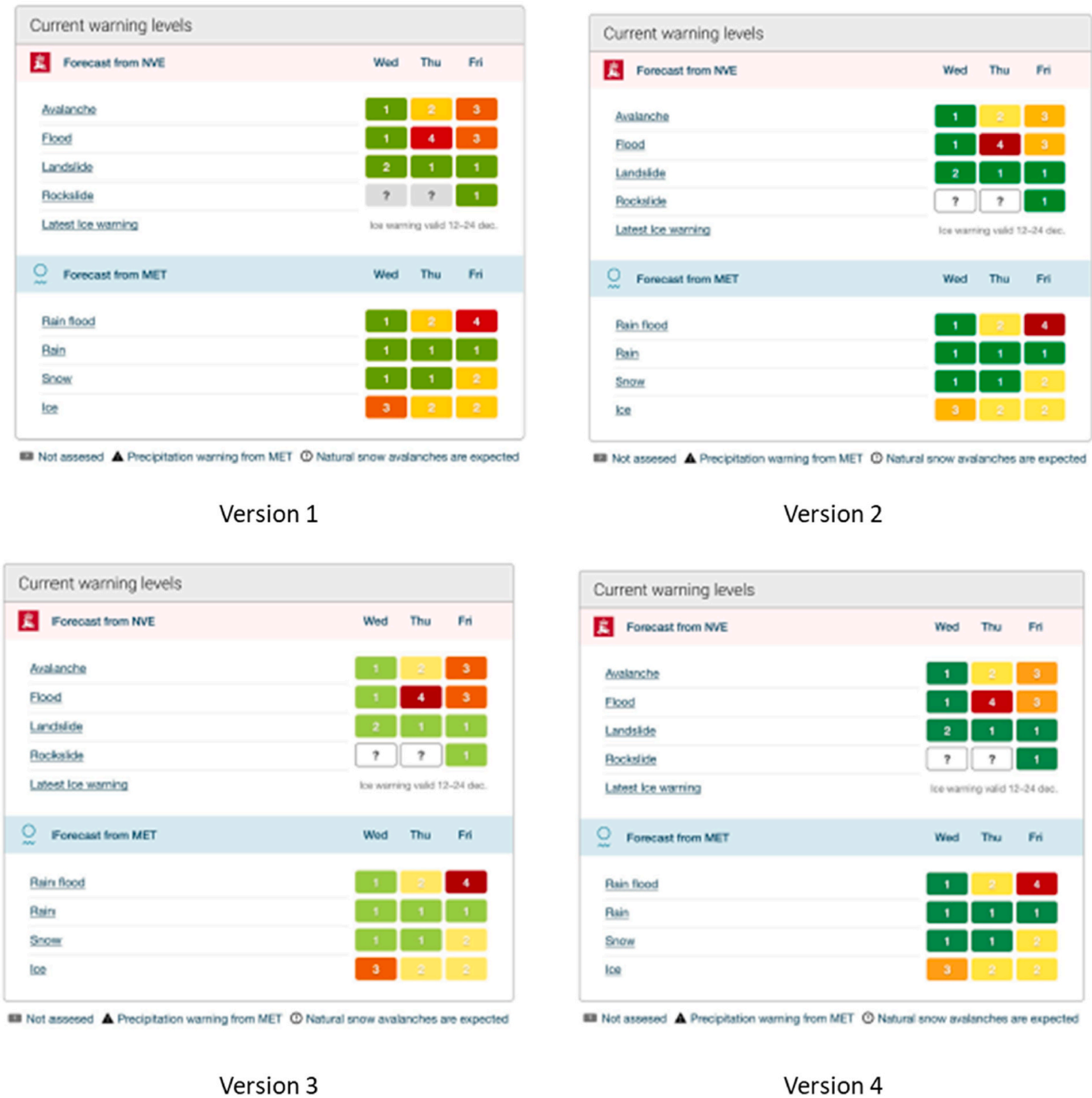


Fig. 3. The four versions of the colour palette, where version 1 shows the Varsom colours as per 2020.

For piloting, we pushed the green and red quite far towards blue to check how far our starting point could be. From the initial feedback that the red was too purple and the green too turquoise, we ended up with three palettes and putting weight on different issues concerning hue, lightness, and contrast for each of them. The Varsom colours (version 1) is shown together with the three alternative versions in Fig. 3.

Feedback from the participants in survey 1 disclosed a need for further refinement of the colours in the new version (version 4) that scored best in survey 1, especially with respect to the use of yellow. As described further below, in survey 2, we tested more alternative versions, including a refined version of version 4 from survey 2.

2.2.3. Three versions of the legend

Persons with CVD have reduced success when they search for colour coded targets in a distractive background [30], thus the simpler and more intuitive the legend is, the more effective. Another challenge is the risk of not understanding the intended message on the warning display even if they notice and encode the words or graphics [31]. To reduce the risk of confusion for CVD users, we incorporated signal words (explanations) for each level in two new versions (Fig. 4), providing a total of three legends to test:

1. Legend as is on Varsom.no
2. New version with numbered labels on top of coloured squares: The squares in this version look the same as the labels in the overview. To minimise confusion, we added the word “danger” next to the colour labels and named each label with the exact level of the danger (low, moderate, considerable, and high).
3. New version with numbered labels on top of coloured squares with proportional sizes: Coloured squares increasing proportionally with the danger level, i.e., longer rectangular shapes indicate higher danger. By increasing square lengths proportionally with danger, the design aims to transfer the traffic light symbolism in a new visual presentation which in this case can be perceived regardless of colour vision.

2.2.4. Four versions of the map

Bartels and van Beurden [10] note the strong visual impact of maps, and how the incorrect use of some cartographic techniques can lead to wrong interpretations of the message. Jenny and Kelso [5] pointed out three principles to consider when creating greater clarity on maps. Firstly, choose an unambiguous colour combination. Secondly, use alternative visual variables, and thirdly, directly annotate features. The authors refer to a combination of shifting the hue and using lines or geometrical shapes as the best combination. We followed the already established traffic light convention. The second principle was implemented in versions 1 and 2 of the maps, and the third principle was implemented in version 3 of the maps. For all versions we had to keep in mind that the maps were to be frequently viewed on the small display of a mobile phone. Thus, we had to be cautious on how the design worked both in small and large scale. We developed pilots of all versions, which we piloted on a small sample of persons before we finalised the different versions which are shown in Fig. 5 and are summarised as follows:

1. Map as is on Varsom.no. We used colours only.
2. New version with different patterns according to danger levels. We chose to test triangle, stripes, squares, and plain colour design on the pattern maps to represent each colour. Taking a mobile view of the map into account, a challenge could be that the pattern was too detailed for the size and resolution of the interface.
3. New version with different outlines according to danger levels. Working out the map versions required diligence, and the accuracy with respect to sizes and proportions was crucial, especially concerning the version with outlines. Making great designs on a large scale on the computer was not enough, as this did not represent the true picture of how it would look and be used. We ended up making thicker lines than we initially thought we need. Thicker lines gave a better match with the flexible use on both phone and laptop screens. We also paid attention to the risk of unwanted qualitative or quantitative meaning of the different lines, such as dash, solid and dots [5].
4. New version with annotated numbers according to danger levels. Okabe and Ito [25] developed guidelines on how to make figures and presentations that are friendly to CVD users. Okabe and Ito [25] show how much better the Paris subway map works, when the lines are made thicker and the names on the lines are placed within the map rather than in separate keys. Inspired by this, we showed the numbers representing danger levels on top of the regions and added a legend, although it was strictly not needed for this version.

Fig. 4. The three versions of the legend: Version 1: The legend as presented on Varsom.no before 2020, without a direct link to what each component means. Version 2: New version with annotated numbers on top of squares aiming to reduce confusion by maintaining the original shape. Version 3: New version with annotated numbers on top of squares with sizes proportional to the danger level.

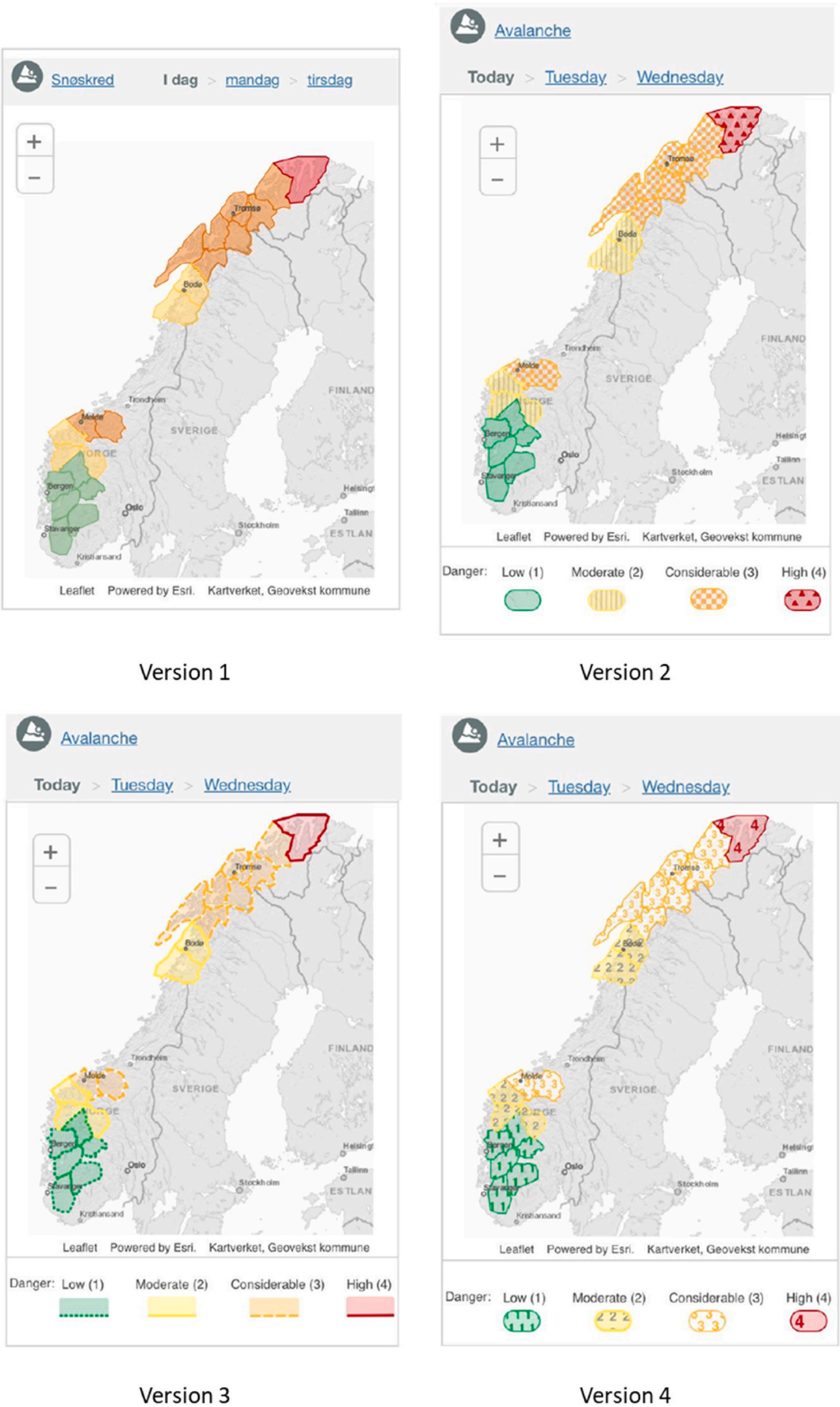


Fig. 5. Illustrations on the four versions of maps tested in the experiment: Discrimination of danger levels using colours only (version 1), patterns (version 2), lines (version 3) and annotating features (version 4).

2.2.5. Test criteria

Participants were presented with the four versions of colour palettes, three versions of legends and four versions of maps. For each version they were asked how well it worked for them. Rating was from very poor to very well on a 5-point Likert scale. They were asked to justify why, and to check "Yes", "No" and "I do not know" on a set of additional statements, e.g. "The legend is intuitive". All participants were asked which palette version, legend version, and map version they favoured. The CVD participants were also asked if they had previous experiences with digital CVD filters, and if these were in demand. The FCV participants were asked if they considered any of the colours to be too far away from what they recognize as green, yellow, orange and red. The answers would indicate where the border lies between what is acceptable and not when it comes to adjusting the original palette.

2.2.6. Analysis

We analysed the results by pooling the CVD group into one entity and comparing them to the FCV group. Data analysis and visualization was performed in R [32] where ratings were assessed as a percentage of each group's respondents. Statistical tests (general linear models) were also used to measure the significance of any differences in the resulting distributions. Analysis is separate for colour palettes, legends, and maps.

2.3. Survey 1 results

2.3.1. Colour palettes

The version 4 of the colour palettes (Fig. 3), designed with CVD in mind, received positive ratings from both the CVD and FCV group (Fig. 6). Forty-two percent of the CVD group rated version 4 positively (well or very well), none rated it as highly negative (very poorly) but 33% rated it negatively (poorly). Sixty-four percent of the FCV group rated version 4 positively, and only 9% rated it negatively. Version 1 works also well for the FCV group, whereas version 2 received the next highest score in the CVD group.

The preferences were reflected in the statistical analysis, i.e., the four versions of the colour palettes were rated significantly differently, $F(3,230) = 4.35$, $p = .005$. The CVD and FCV groups differed in their rating, $F(1,230) = 32.086$, $p < .0001$, and there was a significant interaction, $F(3,230) = 3.968$, $p = .0088$. Post-hoc Tukey tests showed that the CVD and FCV group did not differ in their rating of version 4, $p = .1422$, rating of version 3, $p = .8125$, version 2, $p = .8752$, but did on their rating for version 1, $p < .01$. Thus, version 1 worked better for FCV than for CVD and version 4 was rated highest by both groups.

2.3.2. Custom filters

We asked CVD participants how suitable it would be to add a custom filter and the results show that more than half (54%) preferred a dedicated filter button incorporated on the web page (Fig. 7). Twenty-nine percent choose a filter button over the option with adjusted colours. This could indicate that persons with CVD appreciate this token of being included or that it is simply an easier and better alternative. Very few of the respondents (8%) used their own filter and thus did not need a custom filter on the web pages. Twenty-nine percent reported negative experiences with such adaptations. One participant commented on the issue of a dedicated filter for CVD: "Difficult. Green, yellow, orange, and red are so incorporated that I think it makes no sense to change colours. Better to adjust colour and contrast." Another feedback was that "I generally interpret the normal colours OK". This illustrates that even though many CVD users mix up green and red, they have gotten used to the traffic light convention and favour this to a certain extent. Ordinal logistic regression yielded a significant difference between the preference of "own filter" and the reference group "liking a filter button" ($t = 2.408$, $p = .016$).

2.3.3. Legends

Two alternative versions of the legends (annotated numbers and proportional sizes) were tested against the legend used on Varsom (colours with numbers separate) (Fig. 4). The participants choose between poorly, well enough, and well, when asked how the legend worked for them. Both groups favoured version 2 and 3 (Fig. 8). These two versions received the lowest "poorly" ranking in both groups. For 81% in the CVD group and for 98% in the FCV group version 2 (legend with annotated numbers) worked well or well

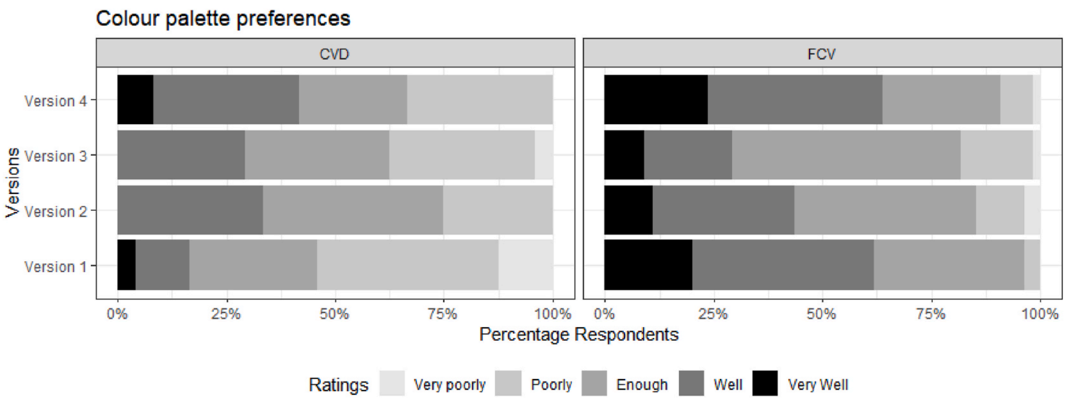


Fig. 6. Diagram showing how well the different colour palettes worked, grouped into CVD and FCV respondents: Version 1 is Varsom maps, while versions 2, 3, and 4 were created for this survey (see Fig. 1).

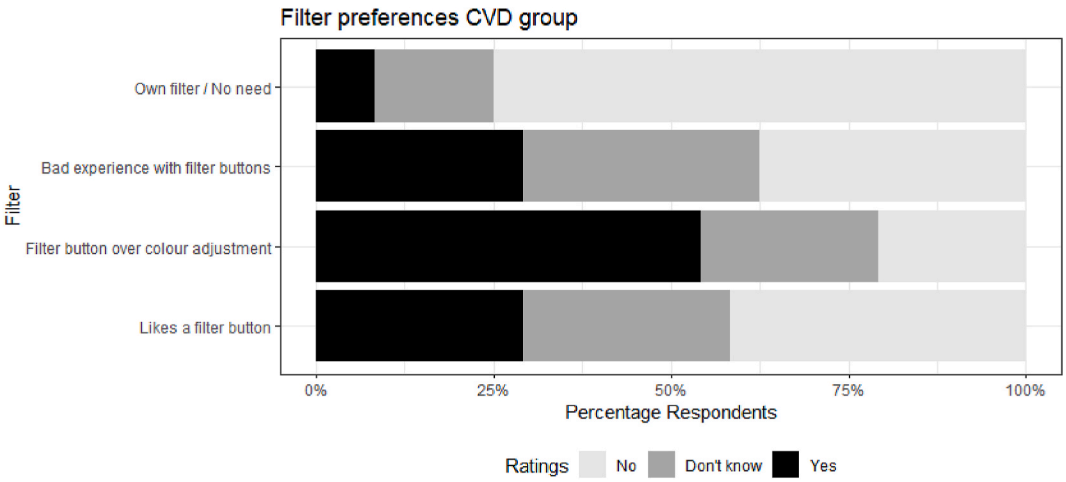


Fig. 7. Diagram showing CVD respondents' feedback on filter options.

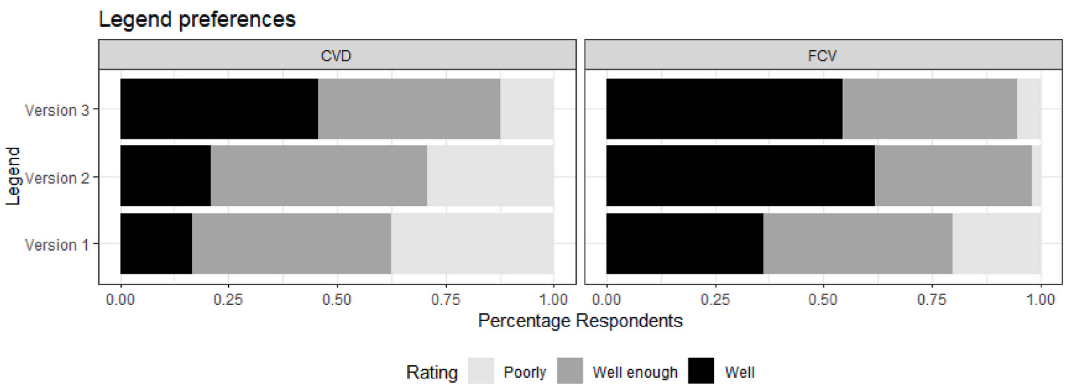


Fig. 8. Diagrams showing how well the different legends worked for participants with FCV and CVD. Version 1 is the one used on Varsom, version 2 has annotated numbers, and version 3 has annotated numbers and proportional sizes.

enough. For 87% in the CVD group and for 95% in the FCV group version 3 (legend with annotated numbers and proportional sizes) worked well or well enough. Thirty-eight percent of the CVD group and 20% of the FCV group responded that version 1 (Varsom legend) worked poorly. Ordinal logistic regression yielded a main effect of group ($t = 2.207$, $p = .027$), version 3 differed from version 1 ($t = 2.704$, $p = .007$), but there was no significant interaction ($p > .19$).

The results indicated that CVD participants favoured version 3, probably because it somehow translated the traffic light into

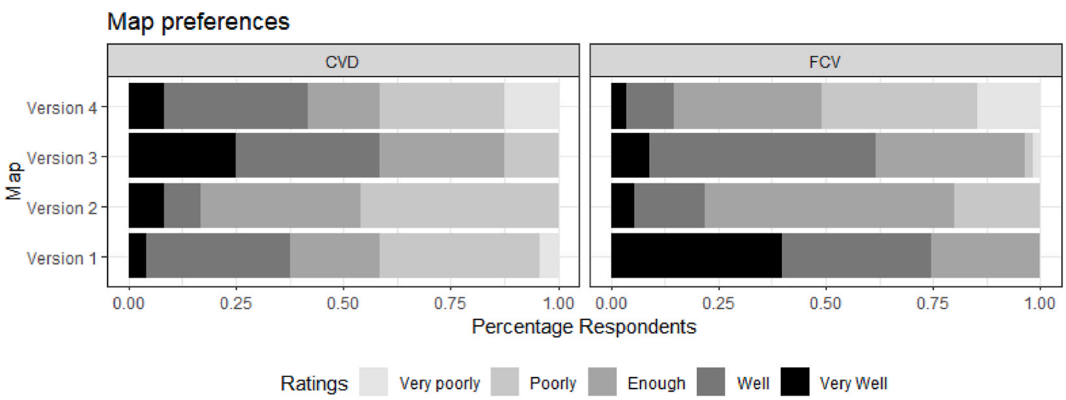


Fig. 9. Diagram showing how well the different map versions worked, grouped into CVD and FCV respondents: Version 1 is Varsom maps, 2 has patterns, 3 has lines, and 4 has numbers.

proportional square sizes according to the danger level. It established something they did not get from the traffic light scale – a parallel. One of the participants commented that “It was too much of a good thing”. The results suggest a way forwards for improving the design of the legend.

2.3.4. Danger maps

Three alternative versions of maps with patterns, lines, and annotated numbers were tested against the colours-only map used on Varsom (Fig. 5) and the results are shown in Fig. 9. The FCV group clearly preferred the colour map (map version 1, current Varsom version, 76%) to the other maps (none more than 9%). The number map (version 4) scored lower among persons with FCV, in fact 51% considered that it worked poorly or very poorly. As many as 78% considered the number map (version 4) messy, while 33% considered the pattern map (version 2) messy. The CVD group preferred the patterned map (version 2) (58% rated it as very well or well) over the version with numbers (version 4), followed by the colours-only map (version 1) and least liked is the map with lines (version 3). There was a main effect of colour vision ($F(1,308) = 4.907$, $p = .027$), a main effect for map ($F(3, 308) = 28.146$, $p < .001$), and a significant interaction ($F(3, 308) = 9.711$, $p <. 001$). Post-hoc Tukey yielded the following significant differences; within the FCV group the rating of the colour map (version 1) differed from the line map (version 3) and number map (version 4) but not the pattern map (version 2) (p’s < 0.001); within the CVD group the line map (version 3) differed from the pattern map (version 2) ($t = 3.5$, $p < .012$); the two groups rated the colour map (version 1) differently ($t = 5.349$, $p < .001$).

All in all, the pattern map (version 2) was the best candidate for an alternative map design. However, we recommend exploring what caused the messy appearance of the number map (version 4) and if this could be amended. An obvious strength of the number map (version 4) is that the danger levels are coded into the currently used map, rendering the legend redundant.

3. Survey 2: Colour follow-up and ATES maps

3.1. Colour palettes follow-up

In survey 2, we tested six different versions of how to display avalanche terrain thematic information on maps using the Avalanche terrain exposure scale (ATES). We also included a test of danger colours, as a follow up to survey 1, based on the following rationale. Survey 1 showed that version 4 of the colour palette (Fig. 3) was favoured by both groups *and* scored high on user satisfaction, however some respondents commented that especially the yellow colour was suboptimal in this version. Therefore, we improved this palette and tested it with a larger international sample in survey 2, and compared it directly against the Varsom colours and two commonly

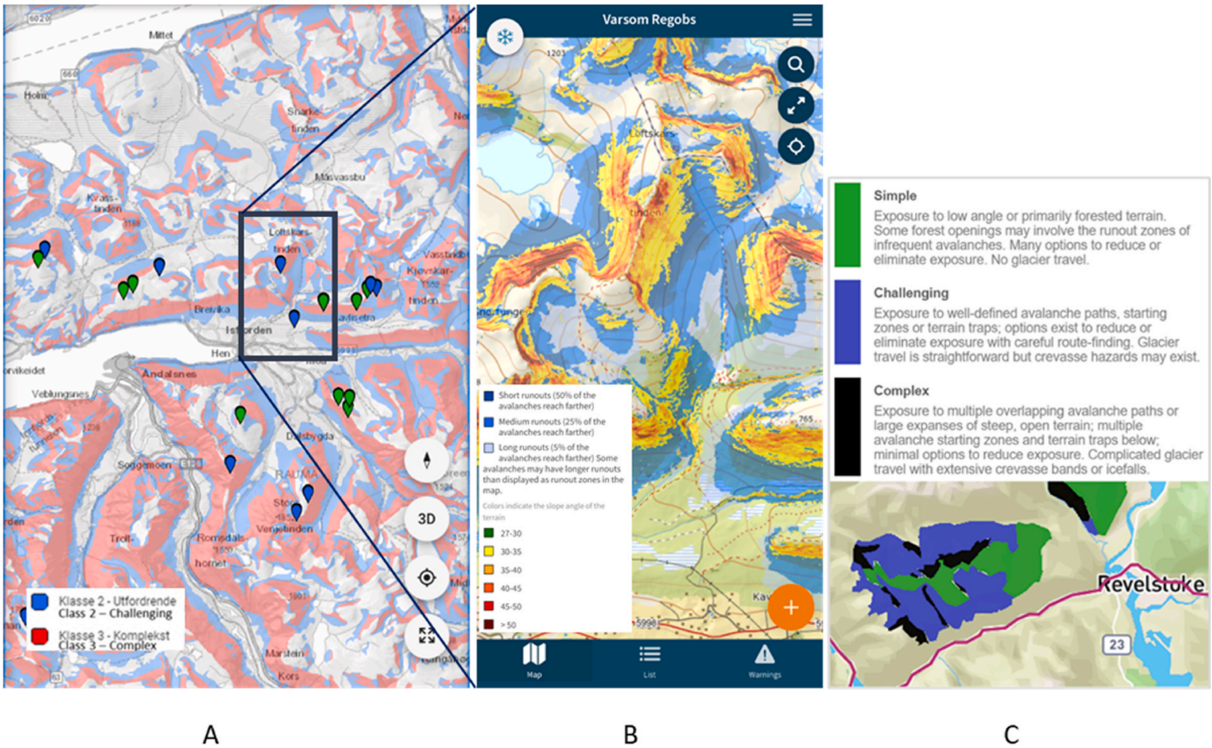


Fig. 10. Examples of ATES and avalanche terrain maps. A: The map show zones (areas) and trips (pins) classified as simple (green, pins only), challenging (blue) and complex (red) on top of a grayscale topographic map in around Romsdalen, Møre and Romsdalen county in Norway. The trips are shown as lines with points of attention when zoomed further in. B: The Varsom Regobs app is currently not showing ATES, but rather communicate avalanche terrain by displaying a steepness map with slopes steeper than 30° (five classes from yellow to dark red) together with modelled runouts (three classes of blue according to runout frequency). C: The public description of ATES classes and an example of an ATES map outside Revelstoke, British Columbia in Canada.

used colour palettes for communicating avalanche danger (the EAWS colours) and severe weather alerts (the Meteoalarm colours). Adding these questions to survey 2 allowed us to improve on the results from survey 1, and critically test the results against colour palettes that are frequently used internationally for communicating natural hazards.

3.2. Adopting Avalanche terrain exposure scale (ATES) communication

ATES (also known as KAST in Norwegian) is used to classify terrain according to how exposed it is to avalanches [21]. ATES is used either for routes in a guidebook or a list, or for showing zones of different classes on a map [33]. ATES has three classes, where 1-simple is coloured green, 2-challenging is coloured blue, and 3-complex black. These three colours, and red, are commonly used for rating ski run difficulty in Europe (green = beginner, blue = easy, red = intermediate, and black = expert).

Ongoing work between Parks Canada, Avalanche Canada, Simon Fraser University (SFU), Montana State University (MSU) and NVE on improving ATES, aims to revise ATES and improve methods for automatic ATES mapping of entire countries. Two new classes are planned for the revised version of ATES: class 0 for non-avalanche terrain and class 4 for extreme terrain where even a small avalanche may be fatal. The first automatic nation-wide ATES maps were published in 2020 [34] and are available as AutoKAST on Varsom.no (https://temakart.nve.no/link/?link=kast). Fig. 10 shows examples of how ATES and avalanche terrain is communicated in Norway and Canada.

ATES information is often shown on maps or remote sensing imagery, which makes blending of colours even more problematic. We developed six different versions of colours palettes/patterns to test how to best communicate ATES information on maps by exploring how intuitive and separable the different versions were, and which was most and least likeable.

In survey 2, we developed and tested colour scales and patterns applicable to showing ATES information on maps. We aimed at understanding which of the versions work better or worse for user from different countries (education, culture and environment may differ), users with different background in terms of experience or avalanche education, or with and without CVD.

3.3. Methods

3.3.1. Participants and recruitment

The second survey was designed in collaboration with scientist and avalanche professionals at Avalanche Canada, Parks Canada, SFU, MSU, UiT The Arctic University of Norway, and NVE. It was in English, designed for international participation, and was developed as an iterative process with informal testing on several people. The survey was implemented in the Qualtrics software. This survey introduced ATES and the ongoing revision briefly. We asked for additional information, such as country of residence, gender, level of avalanche training, number of years and days per season working or recreating in avalanche terrain. We also asked if the respondent had full colour vision or colour vision deficiency, degree of familiarity with ATES and if the respondent had any other feedback to provide on the survey.

The survey was promoted as a news article on Varsom.no, and in relevant social media channels operated by NVE, Avalanche Canada, Parks Canada, MSU, SFU, the New Zealand Avalanche Dispatch, and at two Facebook-groups dedicated to people with vision deficiency. It was also promoted by several members of the European Avalanche Warning Services (EAWS), the American Avalanche Association (https://theavalanchereview.org/research-ask-ates-survey/) and https://atesmaps.org/.

The second survey attracted as many as 1488 responses between 11 March and June 30, 2021 of which 960 responses consented and were complete and thus selected for the subsequent analysis. 860 had FCV, 84 had CVD and 16 did not know or did not indicate their vision. A question on traffic light colours was added to the survey on 25 March, and 68 respondents with CVD completed this test. As noted above, this question was a follow-up to the colour palette survey in survey 1, to allow us test these on more respondents and to test further colour palettes. Table 1 provides the demographics. The sample had a median of 9 years of experience working or recreating in avalanche terrain (average 11.86) and spent a median of 20 days per season in avalanche terrain (average 34.73 days).

3.3.2. Four versions of the colour palette (follow-up from survey 1)

As pointed out previously, the feedback from the participants in survey 1 disclosed a need for further refinement of the colours in the new version of the colour palette (version 4) which scored best in survey 1, especially with respect to the use of yellow. We engaged a user experience designer, who further improved the colours to account for this weakness. He ended up adjusting the green, the yellow and the orange. In this second survey, we tested the four alternative versions shown in Fig. 11. Panel 1 features the EAWS colours, panel 2 the improved version 4 from survey 1, panel 3 the Varsom colours, and panel 4 the Meteoalarm colours. The respondents were shown the four versions in one panel and asked to identify the version with the most suitable and least suitable colours, permitting more than one answer.

3.3.3. Six versions of the ATES map

The current version of ATES uses the three colours: green (1-Simple), blue (2-Challenging) and black (3-Complex), while the map-

Table 1
Demographics for survey 2. CVD-DC denotes CVD participants responding to the danger colour (DC) palette test.

Gender	Women: n = 223	Men: n = 716	Unknown/other: n = 4	
Colour vision	FCV: n = 860	CVD: n = 84	CVD-DC: n = 68	Unknown: n = 16
Avalanche education	None: n = 155	Basic: n = 342	Advanced: n = 204	Professional: n = 243
Country	Norway: n = 344	Canada: n = 355	New Zealand: n = 31	Others*: 222

(*) Details for countries: US (50), Sweden (18), Spain (21), France (10), Andorra (1), Other (122).

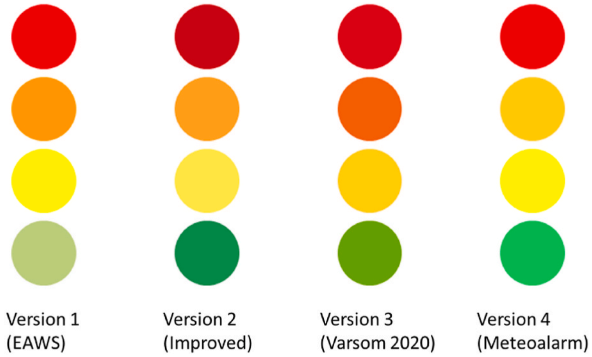


Fig. 11. The four traffic light colour palettes tested in survey 2: 1. Palette used by EAWS for avalanche danger levels, 2. Improved palette based on version 4 from survey 1, 3. Palette used by Varsom, and 4. Palette used by Meteoalarm.

based version of KAST in Norway uses: no colour (i.e., transparent) for 1-Simple, blue for 2-Challenging and red for 3-Complex. Previously, ATES has primarily been used to give specific routes a rating and colour in lists published in brochures and guidebooks. However, increasingly ATES routes are now also presented spatially on maps, where the ATES classes (colours) may be

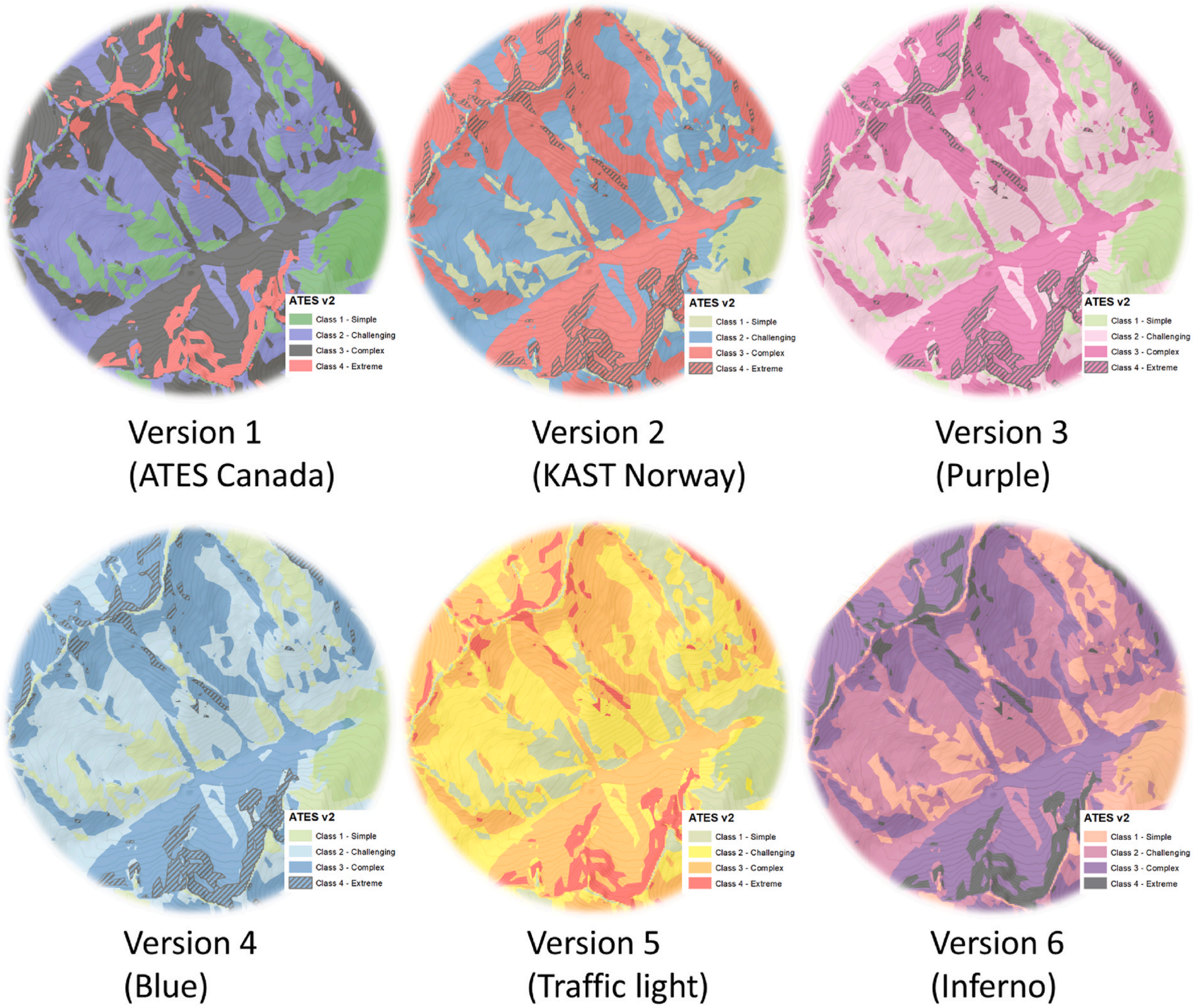


Fig. 12. The six different map versions of the ATES presented in survey 2. Version 1: Colours currently used for ATES in Canada with new class 4 in red. Version 2: Colours currently used for KAST in Norway with new class 4 in red and black lines. Version 3: Shades of pink from PiYG. Version 4: Shades of blue from RdYlBu. Version 5. Colours from Meteoalarm. Version 6: Inferno multi-hued scale.

presented overlaid on topographic maps and aerial or satellite imagery to show where the different ATES-classified routes are in the terrain. Development of zonal ATES for specific areas [33] or nation-wide zonal ATES maps [34], and the ongoing development of the next version of ATES with two more classes calls for reviewing and testing the use of colours and patterns to find out which are the better way of communicating ATES classes on maps.

We developed a set of six alternative map versions for testing (Fig. 12), based on current practices in Canada and Norway, the traffic light colour palette, two multihued colour-blind-friendly palettes (RdYlBu and PiYG) for maps from colorbrewer2.org [41] and one single-hue self-developed palette. We chose a map extent which represents about 7 km distance from west to east on a mobile phone at scale 1: 50,000, and a transparency of 50% for the ATES colours which are overlaid on a topographic map. All colour codes for ATES maps, as well as the traffic light colours used in the tests are listed in the Appendix. Here is an overview of the ATES map versions tested:

1. Green-blue-black-red: Colours currently used in Canada, except that the new class 4 is shown in red.
2. Green-blue-red-blackhatched: Colours currently used in Norway, except that the new class 4 is shown with diagonal black lines on red fill. We picked red and blue from the 4-class RdYlBu and green from the 4-class PiYG.
3. Green-pink1-pink2-blackhatched: We picked two shades of pink and green from the 4-class PiYG.
4. Green-blue1-blue2-blackhatched colours. We picked two shades of blue from the 4-class RdYlBu and green from the 4-class PiYG.
5. Green-yellow-orange-red: We picked the green-yellow-orange-red-colours from Meteoalarm.
6. Green-purple1-purple2-blackhatched: We picked shades of purple, pink and peach based on the Inferno multi-hued scale [35].

We developed and tested internally several other multi- and single hued palettes but reduced the number of versions to six to keep the completion time of the web-based survey between five and 10 min to reduce the chance of having participants quit mid-way in the survey due to fatigue. There is always a balance between the desire to test many options in detail versus getting a high number of participants to complete surveys. As we already conducted survey 1 with more details on colours with fewer participants, we did not want to compromise on the number of participants in survey 2. We used green from the Colorbrewer2.org 4-class PiYG in most of the map versions, as this colour worked well with the other map colours. We did not include any class 0 terrain, as we thought it would be too many colours to test at one go and it would be suitable to use white or transparent to show this class on maps. White has the intuitive association with peace and absence of danger in certain cultures, while in others white may be associated with death (more on this topic in section 4.2). By not showing this class on the map using partial or solid fill colour, the user will benefit from being able to see other features of interest on topographic maps and aerial or satellite imagery when planning their outings. We also attempted using cross-hatching and several patterns supplied by ArcGIS from the Environmental Systems Research Institute (ESRI) to communicate class 0 and 1 on maps, with and without solid fill, but the results were considered sub-optimal.

3.3.4. Test criteria

Each respondent was first shown each of the six map versions of the ATES maps in random order and asked to rate it on a scale from 0 to 10 according to three factors (intuitive, separation, preference):

1. How intuitive is the colour scale in terms of avalanche-exposed terrain? (0 = Not at all, 10 = Extremely intuitive)
2. How easy is it to separate individual classes? (0 = Extremely difficult, 10 = Extremely easy)
3. How much do you like the colour scale? (0 = Not at all, 10 = Love it)

In other words, each version could be scored up to 10 points for each factor or a total of 30 points for all three factors. Secondly, the respondents were shown all six map versions together in one panel and asked to identify the map with the most suitable and least suitable colours, permitting more than one answer. We also explained that ATES classification refers to terrain and says nothing about snow conditions and asked to rate how likely it would be that they or others would misinterpret the colour scale as an indication of

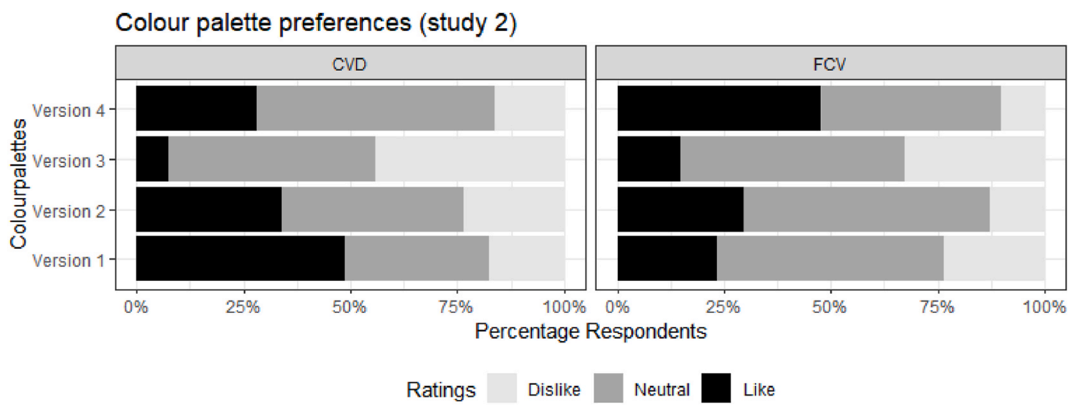


Fig. 13. Diagram showing how many likes or dislikes the different colour versions 1–4 received. Left shows results for CVD respondents, while right shows results for FCV respondents. Version 1 has the EAWS colours. Version 2 is the improved palette based on version 4 from survey 1. Version 3 has the Varsom colours as per 2020. Version 4 has the Meteoalarm colours.

avalanche danger if the colour scale in map version 5 (traffic light colours) was used for ATES.

3.3.5. Analysis

We analysed the results by pooling the CVD group into one entity and comparing them to the FVD group. We used general linear models with Greenhouse-Geisser correction when the assumption of sphericity was violated. Data analysis and visualization was performed in R [32].

3.4. Survey 2 results

3.4.1. Colour palettes follow-up

In survey 2, 68 CVD and 545 FCV respondents chose which of the four palettes (from Fig. 11) they liked and disliked. The results show that version 4 (Meteoalarm colours) was favoured (most liked *and* least disliked) by FCV respondents (Fig. 13). CVD respondents favoured version 1 (EAWS colours), albeit it is noted that the number disliking versions 1 and 4 was similar. Version 3 (Varsom colours) was the least favoured version independent of colour vision. The results for the new palette (version 2) are ambiguous for CVD respondents, being the second most liked as well as the second most disliked. Ordinal logistic regression yielded a main effect for group ($t = 3.812$, $p < .001$), a main effect for the versions (version 1 differed from version 3, $t = 5.953$, $p < .001$, but not from version 2 ($p = .056$) and version 4 ($p = .057$). The interactions were significant; the groups differed in rating the versions (smallest $p = .002$). As Fig. 13 shows, version 4 receives overall the highest score and version 3 the lowest (neutral + like).

3.4.2. ATES maps

Next, we present the results from testing the six versions of the ATES maps. Firstly, ATES maps were tested by asking three questions for each of the six map versions (Fig. 12) (which were presented in random order to the respondent). The results are shown in Fig. 14. Map version 2 was rated highest (above 19) by both the CVD and FCV groups when considering total scores, while map version 5 was rated just as high as map version 2 by FCV group. All other versions scored between 4 and 7 points lower. Map version 2 scored high on all three individual factors for all groups, while map version 5 scored high with the FCV group only.

A repeated measures ANOVA with the three questions and map as within factor and CVD/FCV as between factor yielded a main effect for map, $F(4.5, 4241.87) = 54.685$, $p < .001$, $\eta^2 = 0.028$, a main effect for question type, $F(1.87, 1760.75) = 181.635$, $p <. 001$, $\eta^2 = 0.014$ but no statistically significant main effect for group, $F(1, 942) = 3.592$, $p = .058$, $\eta^2 = 0.001$. The interaction between group and question was significant, $F(1.87, 1760.75) = 3.413$, $p = .036$, $\eta^2 = 0.00027$, the interaction between group and map was significant, $F(4.5, 4241.87) = 17.332$, $p < .001$, $\eta^2 = 0.009$. The interaction between question and map was significant, $F(8.14, 7664.33) = 22.684$, $p < .001$, $\eta^2 = 0.003$. The three-way interaction between group, question and map was significant, $F(8.14, 7664.33) =$

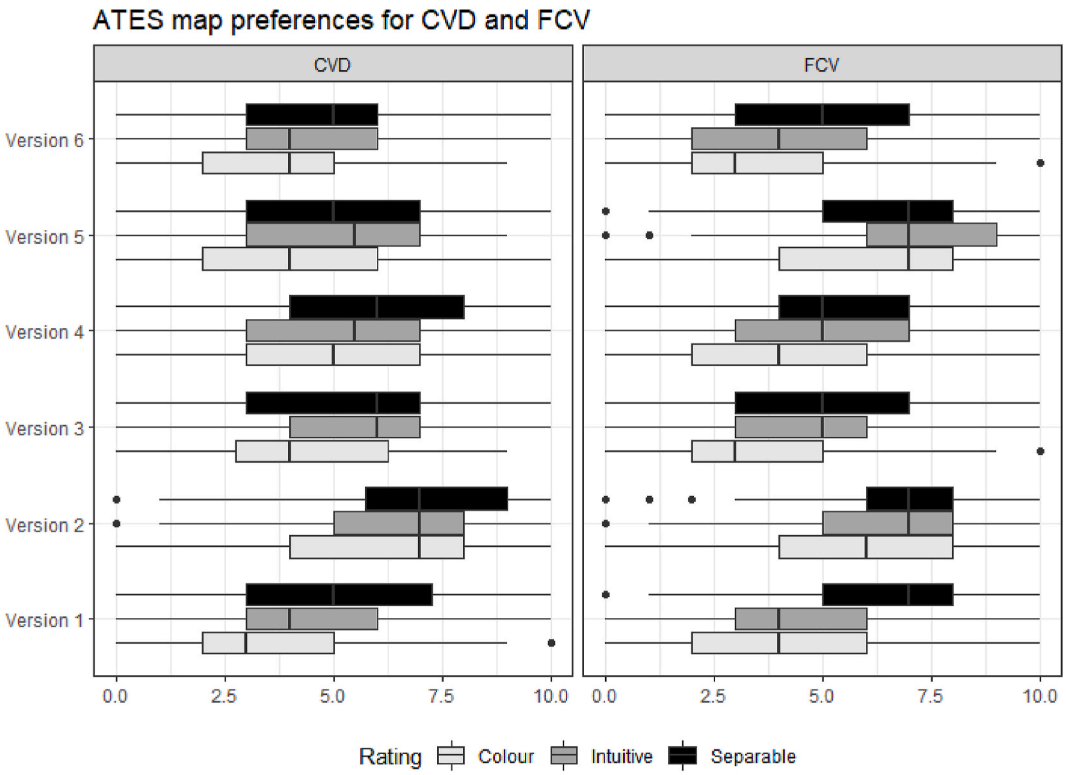


Fig. 14. Diagram showing results from the first test of the six ATES map versions 1–6, grouped into CVD and FCV respondents. The boxplots show the median rating and the interquartile range (25th and 75th percentile).

5.873, $p < .001$, $\eta^2 = 0.008$. As can be seen in the figure, the question about colour was rated lowest, followed by intuition and separation. Post-hoc test for maps showed that map versions 2 and 5 were not significantly different ($p = .365$) but these two maps scored higher on all three questions than the other four maps (all p's < 0.0001). Map versions 1 and 4 scored similarly ($p = .162$).

Next, we controlled for familiarity with ATES (scored from 0 to 10) and grouped participants into three country bins, group A included all Norwegians (n = 219), group B included all from New Zealand and Canada (n = 341), and group C included participants from all other countries (n = 383). Six participants did not indicate their country. Being familiar with ATES was not a significant predictor for the rating of the maps, $F(1, 938) = 2.599$, $p = .107$, $\eta^2 = 0.0008$. This is important, as the colours should work equally well for novices and experts. Country was a significant predictor, $F(2, 938) = 9.126$, $p = .00012$, $\eta^2 = 0.006$. The two-way interaction country by question was not significant, $F(3.74, 1752.8) = 1.148$, $p = .331$, $\eta^2 < 0.001$. The two-way interaction between country and map was significant, $F(9.09, 4263.25) = 6.775$, $p < .001$, $\eta^2 = 0.007$. The three-way interaction between country, question and map was also significant, $F(16.26, 7627.32) = 2.325$, $p = .002$, $\eta^2 = 0.0065$. As Fig. 15 shows participants from Canada and New Zealand who are familiar with map version 1 still preferred map version 2 over map version 1, in fact they rated map version 2 higher than the Norwegian group.

The result of a similar analysis is shown in Fig. 15, restricted to either Norwegians (n = 219) or Canadians and New Zealanders (n = 341) and those from remaining countries (n = 383) to see if there were familiarity effects. Map version 2 is probably most familiar to Norwegians, while map version 1 is most familiar to Canadians and New Zealanders.

Secondly, we asked participants to choose which map they liked and disliked the most (while seeing all versions at the same time). The results are shown in Fig. 16. The CVD group liked map version 2 best, followed by map versions 1 and 4. At the same time, they disliked map version 5 the most, followed by map version 1. On the other hand, the FCV group liked map version 5 the most, followed by map version 2. They disliked map version 6 and partly map versions 1, 3 and 4. Grouping data into Norwegians (CVD: n = 32, FCV: n = 312) and Canadians and New Zealanders (CVD: n = 26, FCV: n = 357) shows similar results (Fig. 16B), apart from a smaller proportion of the Norwegian CVD participants disliking map E and a larger proportion of Canadian/NZ participants disliking map versions 5 and 6.

Map version 5 is based on the traffic light colours, which are used to communicate avalanche danger levels. Avalanche danger level is related to the likelihood and size of avalanches, and thus a property mainly varying in time rather than a function of terrain. ATES classes, on the other hand, more related to the terrain and thus a more static property. To investigate if using the same colours on these two different products may be a problem, we asked "how likely do you think it is that you or others would misinterpret the colour scale as an indication of avalanche danger if the colour scale in map version 5 (above) was used for ATES/KAST?". About 7% of the respondents think it is very unlikely (score 0 or 1) with misinterpretation, 7% think it is very likely (score 9 or 10), and for 36% it is

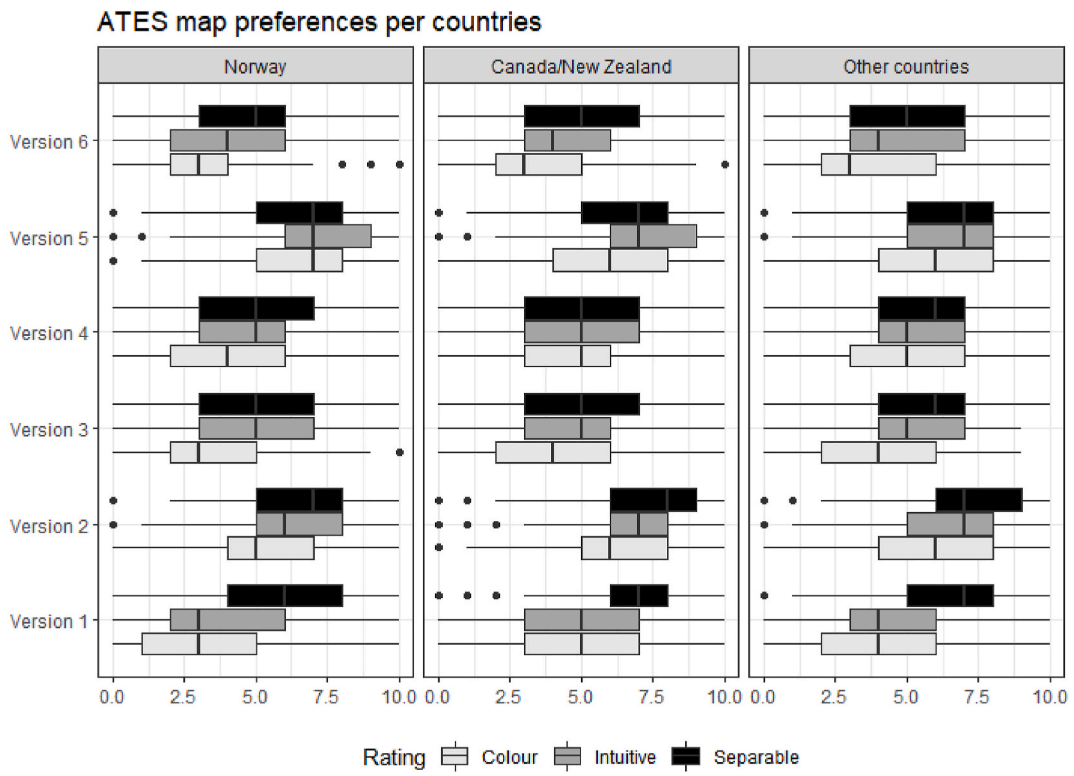


Fig. 15. Diagram showing results from the first test of the six ATES map versions, grouped into countries. The boxplots show the median rating and the interquartile range (25th and 75th percentile).

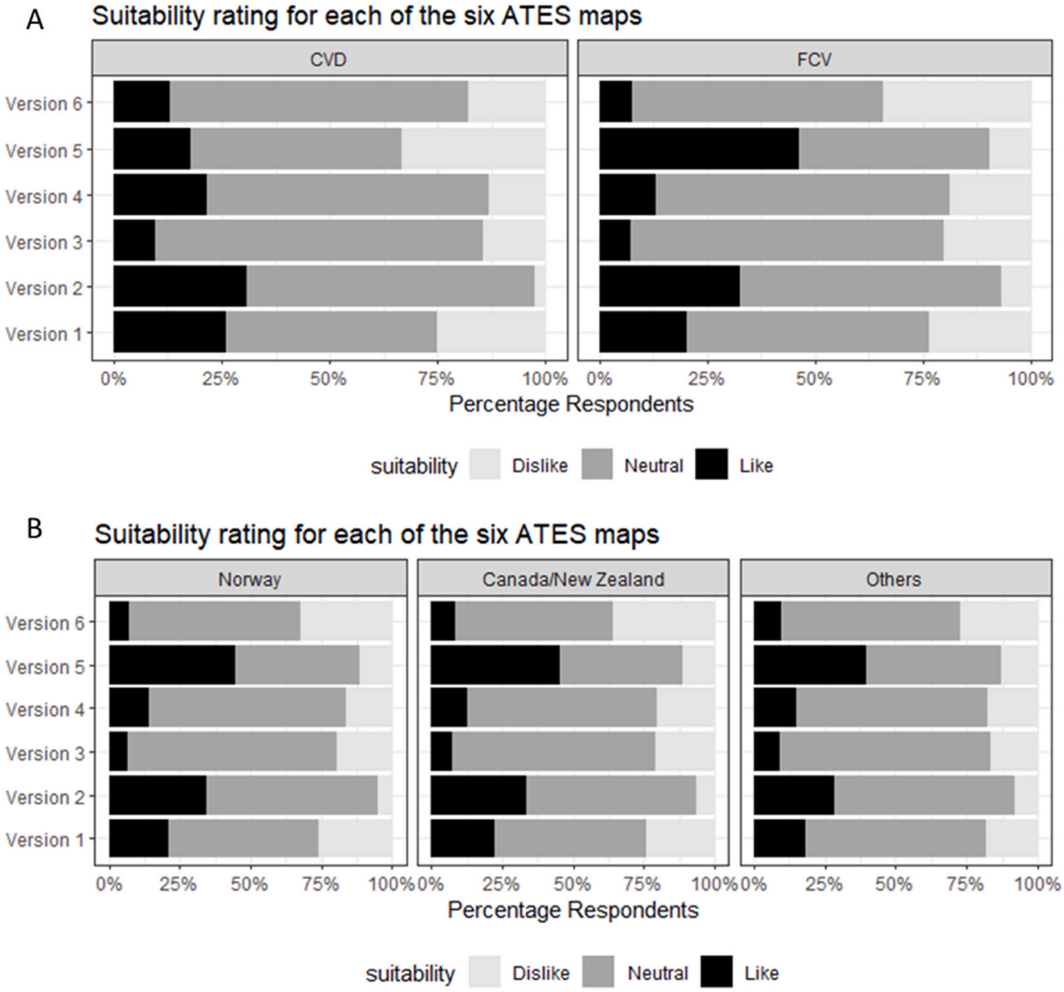


Fig. 16. Diagrams showing how many liked and disliked the six ATES map versions 1–6: A: Results grouped into CVD and FCV respondents. B: Results grouped into countries.

neutral (score 4–6). We grouped the results according to four levels of avalanche education (none = 0 and 3 = high) and split by colour vision and country. As shown in Fig. 17, CVD respondents from Canada and New Zealand considered misinterpretation most likely, and there is a tendency among FCV respondents that the more advanced avalanche education the more they consider misinterpretation likely. This might suggest that they perceive this to be a problem for less experienced users, but not for themselves.

4. Discussion

4.1. Danger colours, legends, and maps

The results of survey 1 showed that more than half of the participants in both user groups favoured a different colour palette scheme (version 4) than the version currently used (version 1). We realized from the data that favouring does not equal to being optimal, as 33% of the CVD group expressed that version 4 worked poorly. We took a closer look at the palette that most persons thought worked best in survey 1 and developed a new colour palette, version 2 in survey 2, to be tested on a much larger Norwegian and international sample of users in survey 2, together with the Varsom colour palette and the colour palettes used by Meteoalarm and EAWS. A recommendation based on the results from both surveys is to use the colour palette used by Meteoalarm (version 4 in Fig. 11). Regarding legends, version 3 which provided colour, size and number information was preferred most by CVD, and received positive ratings by FCV. In line with the WCAG 2.0 we recommend redundancy to ensure unambiguous danger level communication. When it comes to the danger maps, the current standard map was not sufficient for CVD users. They preferred the patterned map (Fig. 5), which received the second highest positive rating among FCV users too.

There were some challenges in this scientific study on how colours, maps and legends could be improved for CVD users, as well as for FCV users. The colours in the warning system should be a well-designed product for persons with normal colour vision, and at the same time they should work for persons with CVD as most of them have trouble in recognising the colours in signal lights [30]. The aim

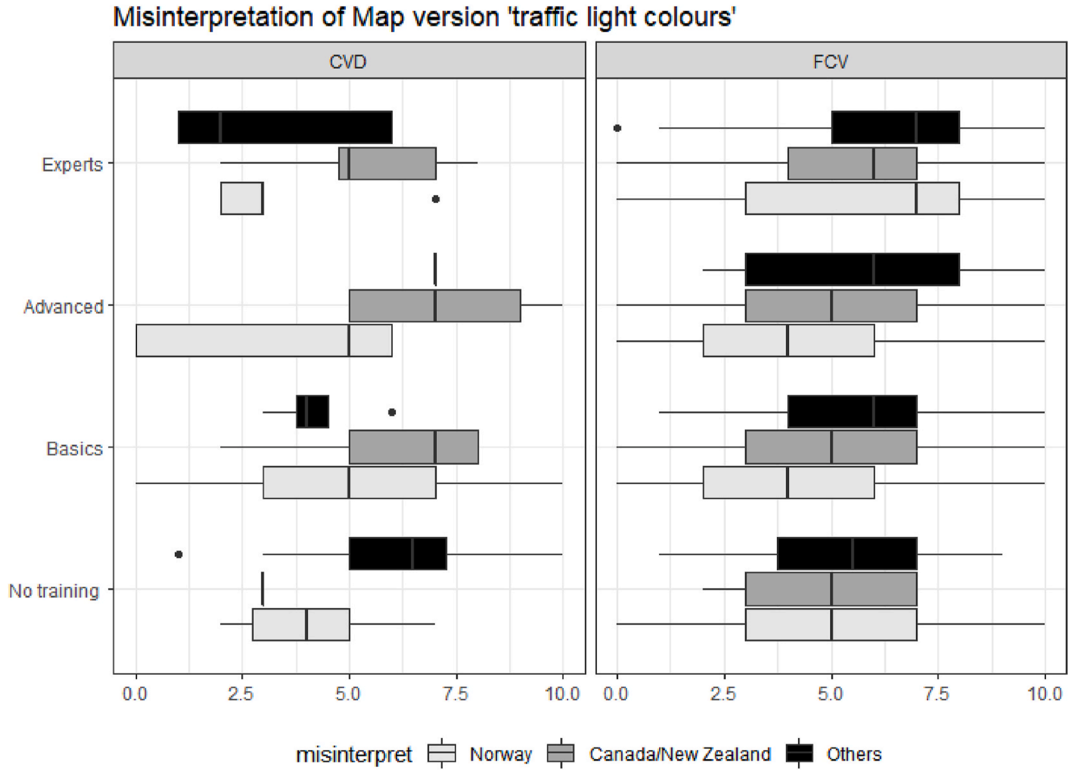


Fig. 17. Box plots of the response to the question "how likely do you think it is that you or others would misinterpret the colour scale as an indication of avalanche danger if the colour scale in map version 5 (above) was used for ATES/KAST?" per avalanche education/training level and separate for respondents from Norway, Canada/New Zealand and other countries.

of this study was to gain insight on how colour coded warning system, following the traffic light scale, could be improved for colour vision deficiency – and at the same time work well for full colour vision. These results have generated more insight into how to (and how not to) communicate using colours and maps in the context of natural hazards. Our observations and analyses have created an understanding of how customisation could be successfully achieved. The feedback on which palette worked best was non-uniform. This may reflect many aspects, e.g., the way persons with CVD perceive colours vary and the colours are different in the eyes of the beholder no matter colour vision. The feedback on the colours raises several questions. E.g., should colours be adjusted, at the expense of those who do not gain from it? For instance, users with FCV would get a product of decreased quality if colours were adjusted to the benefit of CVD users only. The results from the study of new versions of warning maps were more uniform, although colours were involved in the assessment. The different designs of the maps are unique units, which made it easier to interpret the outcome of the user testing. Some of the feedback from persons with FCV was that both the number and pattern maps were messy. This is a natural reaction for a person being used to no extra attributes. We believe in a potential to work more closely on the pattern or number designs to make these more effective.

4.2. ATES maps

The results from testing the different ATES maps showed that the colours (and patterns/symbols) should be reconsidered when revising the ATES. Two versions emerged as the best alternatives according to the test, map version 2 (green, blue, red, and red with diagonal lines) and map version 5 (green, yellow, orange, red and red with diagonal lines). Map version 2 mimics the ski run difficulty signs used in most of Europe and extends the current ATES three-class version with a possible way to display extreme as hatched diagonal lines, like what is used in some countries to alert drivers on the highway (where yellow hatching on the road surface indicate the end of lane when entering or exiting the highway). Albeit not intuitive to all users, this version is somewhat compatible with the current ATES version 1.0, and it will be quite intuitive to skiers coming from ski resorts and venturing into the backcountry and using ATES. Map version 5 is based on the traffic light colours and is also being used for the avalanche danger level scale world-wide. It has a strong cultural basis and is intuitive to most of us. However, it may be confusing for warning services, avalanche instructors and users if two scales presenting different aspects of avalanche risk (avalanche danger and avalanche terrain exposure) are communicated with the same colour palette. Or on the contrary, for some users this may make everything easier to understand. Our results are not decisive. However, based on the extensive feedback received from survey 2 it is obvious that many of our respondents, especially those with higher levels of formal avalanche education, are worried that confusion will be a major challenge if using the same colours.

With this in consideration, and in the context of our results, we propose that the recommended colours for the next version of ATES should be green for class 1-Simple, blue for class 2-Challenging, red for class 3-Complex, and red with black diagonal lines on top for class 4-Extreme. Many respondents liked the use of black hatching on red for extreme, maybe as black is frequently associated with death in the cultures where the surveys were distributed [36,37]. In some Asian and Slavic cultures, white is more commonly associated with death [38] and thus our results may not apply everywhere. Many respondents pointed out that solid black should not be used on maps, as it would render the underlying information, in particular contour lines, unreadable. It should be noted that despite this, current maps of ATES use black for class 3-complex. An alternative to diagonal lines could be diamonds, reassembling the most difficult ski runs. ISO 22324 [20] suggests a checkerboard pattern when presenting black, thus a red-black checkerboard could be an option to lines. Of the two versions that scored best, map version 2 (green, blue, red, and red with diagonal lines) and version 5 (green, yellow, orange, red and red with diagonal lines), version 5 is most in line with the guidelines provided by ISO 22324 [20]; which states that blue should not be used to indicate a safe condition or any other level of hazard. It is worth noting that blue shades are used to display avalanche runout zones on the Varsom Regobs app, suggesting that blue should be replaced by shades of purple to be more in line with guidelines of ISO 22324 [20] stating that purple could be used as a supplementary colour for fatal danger.

Colours for class 0-Non-avalanche were not tested, but we suggest to use white or transparent for this class. Several respondents suggested not using green for class 1 (Simple) due to the problem for people with CVD, the strong association with 100% safety (which is not the case – as class 1 Simple terrain in ATES is still avalanche terrain), and finally the confusion and likeness with other surface types, mainly vegetation, shown as green on topographic maps and aerial and satellite images. A workaround could be to develop a kind of hollow fill to be used for class 1 (Simple). This would be transparent, but still have a border line.

Based on the professional experience of the authors, and discussions with the developers of ATES, it may be legitimate to abstain from displaying class 0 and 1 on maps due to issues such as liability, technical obstacles, or priority of information. Issuing organisations may find it difficult to publish maps "guaranteeing" that such terrain has absolutely no avalanche exposure (relevant for class 0 ATES terrain), since an avalanche accident (due to topographic data errors or lack of details in the map) may represent a potential risk from a lawsuit or loss of reputation. Technical challenges in automatic mapping are also an issue: Currently, Norway is the only country with nation-wide ATES maps generated from an automatic method [34] and during this effort it was difficult to effectively map the limit between class 1 and 0. Thus only class 2 and 3 are shown on publicly available national maps. The effect of low number of displayed classes also has the following two advantages: (a) these maps are less cluttered and easier to read, and (b) the maps show useful information from topographic maps (or satellite/aerial images) where the terrain is less exposed to avalanches. The "less is more" design-criterion is often successful when aiming at effective communication, as is recognising the problem with green for many of the users with CVD: The colour green is easily confused with vegetation (when overlaid on topographic maps) and yellow-red colours (when read by users with CVD). Furthermore, showing colours for class 0 and 1 will make the map rather cluttered, it may be more effective ways to show users areas without avalanche terrain. On the other hand, it would be good to show simple and non-avalanche terrain on a map, so that people know what the safer options are under higher hazard conditions. Without a mapped representation of this relatively safer terrain, people may go into challenging terrain to find something to ski/ride. On the Varsom Regobs app this is catered for with maps on a more detailed scale than ATES, showing potential starting zones in yellow-red colours (terrain stepper than 30°), runout zones in blue colours, and all non-avalanche terrain as a normal topographic map. ISO 22324 [20] states that green is associated with a safe status and should be used to notify people at risk that no action is. We note that this is probably not the case for simple terrain (ATES class 1) or situations with avalanche danger level 1-low.

4.3. Implications for Varsom

This study is a follow up of a previous study on the efficacy of communication of avalanche warnings online [22], which resulted in improving Varsom in 2019. After survey 1 was completed, NVE implemented a new legend on Varsom based on version 2 of the colour palette from survey 1 (Fig. 4). After this change, colours are communicated together with numbers as labels in tables, headings, and legends on Varsom providing easy access to users with and without colour vision deficiency. NVE opted for the legend with one size boxes in the legend (version 2) rather than the legend with proportional sizes (version 3) with the reasoning that this would not under-communicate these lower danger levels to the users of avalanche warnings. Respondents preferred version 3, which visually communicates the increase in danger by showing larger boxes for each danger level number. However, there are other considerations suggesting this solution is not straight forwards when aiming at avoiding accidents. Such an approach may be deceiving in terms of how much the danger increase from one level to another. Results from Winkler et al. [39] suggest that the likelihood of triggering an avalanche (proxy for the risk of backcountry skiers/riders) increased by a factor of 5.5 from danger level 1 to 2, 3.2 from 2 to 3 and not at all from 3 to 4. Furthermore, most fatal avalanche accidents occur in the backcountry at danger levels 2 and 3, not 4 and 5 [40]. Thus, there may be adverse effects from introducing version 4 with proportional size for avalanche danger. Legend 3 may work well for preparedness authorities interested in the size and likelihood of naturally released avalanches, but less so for backcountry recreationalists.

The improvement of maps is on the agenda, but no appropriate and clean design has yet been developed for implementation. It was also considered to implement a new colour palette, version 2 in survey 1 (Fig. 3), but this decision was postponed pending results from survey 2 as the decision-makers wanted more decisive results from a larger sample size of user to base their decisions on. The results from survey 1 and 2 suggest that careful attention need to be paid when using colours, annotation, and legends to communicate danger using maps in general. More specifically, the currently used colours on Varsom should be replaced by the colours used by Meteoalarm (version 4 in survey 2, Fig. 11). Furthermore, an on/off button should be introduced with all danger level maps to enable the user to switch on separable symbols in addition to the colour for each danger level. These symbols may be some type of shading, lines, or dots. Another solution could be to label the maps with the danger level numbers, but rather than cluttering the maps with patterns showing many numbers (used in survey 1, Fig. 5) the regions with the same danger level should be aggregated and label with one danger level number each to make the map more readable (illustrated in Fig. 18). This option also more in line with ISO 22324 [20] which recommends adding supplemental information such as text, numbers, etc. This was not explicitly tested in this study and could be explored in future studies.

The Varsom Regobs app (available on Appstore and Google play) does not currently show ATES maps, but rather terrain steeper than 30° (potential start zones) and runout zones. Introducing ATES as part of this application may be beneficial for some users as an extra layer of information, but it may also be confusing to other users as they must understand how it is different from the current slope angle and runout maps. Another issue is that ATES maps are only suitable at coarser scales, relative to the slope angle and runout maps. The current version of KAST is explicitly set so that users cannot zoom in beyond a given point (approx. scale 1:100,000), which means that for trip planning there is a lot of information, and people can toggle between layers – but at the point of navigating in the terrain, they only have access to the slope angle and runout maps.

4.4. Limitations and future research

These studies addressed several challenges with regards to communicating risk, dangerous conditions and dangerous terrain using colours, maps, and legends. Survey 1 was more exploratory in nature. Getting many CVD respondents engaged and committed to complete such online surveys is difficult. However, the sample size is acceptable. Survey 2 achieved a much higher number of respondents, with different nationalities and level of education and experience. Tests of the efficacy of the different danger colours and ATES map representations relied on the users rating three factors (intuitive, separation, preference) for each version or voting on the version they liked best or worst. We did not test to what degree the different versions helped the user make the right choices, which may have been a more realistic test (but it requires a correct definition of the right choices), or test the understanding and comprehension of the different map versions with a series of choices such as: “circle the zone with the highest danger” and other similar tasks. Another limitation is that the ATES map versions did not test how class 0 may be visualized – how it may be different than class 1 and used together with other maps. We recommend addressing these limitations in future studies.

Topics for future research may also include testing how the use of different colour palettes may negatively affect decision making, e.g., by making it difficult for users of warning and hazard products to identify and respond to the message. Future research and creative design process should aim at developing better standards for communicating warning and hazard products, using complementary or alternative designs.

5. Recommendations

Our results show that the use of colours, legends, and maps on Varsom should be improved:

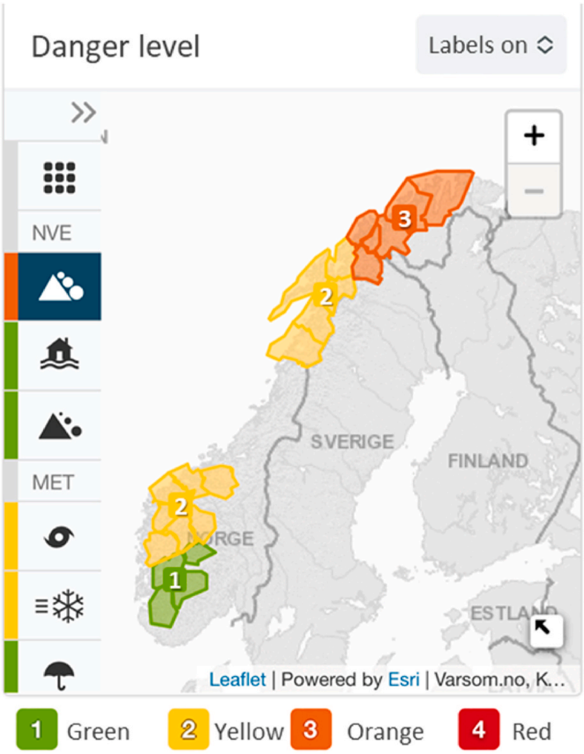


Fig. 18. Illustrated potential improvement of Varsom danger maps for users with CVD, where the user is given the option to label the maps using a labels on/off toggle.

- The *colour palette* used for danger levels on Varsom (version 1 in survey 1, Fig. 3) scored worse than all other palettes tested. It is recommended to abandon the use of the Varsom colour palette as it scored very low in survey 2 (N = 960). The best version appears to be the Meteoalarm (version 4 in survey 2, Fig. 11) colour palette (scored best by full colour vision respondents) or EAWS (version 1 in survey 2, Fig. 11) colour palette (scored best by respondents with colour vision deficiency), but there was no single version which was clearly best for both groups. Considering that probably as many as 90% of the users have full colour vision, and that numbers may be used as labels to show the danger level in most of the display modes (less so for maps), the Meteoalarm colour palette, with numbers as labels, is our recommended version for the largest number of users.
- The *legend* explaining the danger level colours on Varsom (version 1, Fig. 4) scored worse than the two alternative versions presented. It is recommended to change the legend to version 2 (favoured by full colour vision respondents) or 3 (favoured by colour vision deficiency respondents). However, the test population was relatively small and version 3 with proportional size may cause a false sense of safety at lower avalanche danger levels, as most avalanche fatalities occur at danger levels 2 and 3, not 4 and 5 [40]. Thus, we are not able to make a conclusive recommendation apart from not using version 1.
- The *maps* showing the danger levels on Varsom (version 1 in survey 1, Fig. 5) scored very high with full colour vision respondents, but very low with colour vision deficiency respondents. It is recommended to add numbers or patterns to the map, or to add a custom toggle for users with colour vision deficiency. As the test population was relatively small and the results deviated between CVD and FCV users, we recommend further studies on this topic to investigate design options.

Our results show that the colours (and patterns/symbols) should be reconsidered when revising ATES:

- The map version with the highest score for ATES, and least likely to cause confusion with the avalanche danger scale was that inspired by the colours used for ski run difficulty in most of Europe (version 2 in survey 2, Fig. 12), and our recommendation for the next version of ATES is to use green for class 1, blue for class 2, red for class 3 and black diagonal lines on top of red for class 4.

We recommend further studies on how to communicate ATES classes 0 and 1 on maps, as well as considering the option to not show class 0 and 1 on maps. We discussed issues related to showing ATES classes 0 and 1 on maps. These may be easier to read for many users when are left out, recognising that it lacks information about how to fully avoid avalanche terrain. White or green with white hatching could be used for class 0. Although green is recommended for class 1, it is difficult to separate from vegetation or other greenish themes on topographic maps and satellite or areal imagery – as well as to users with colour vision deficiency. Further research and development are recommended to resolve these issues.

We recommend that any person or organization communicating information about dangers or risk, pays special attention to, and considers testing of how the use of colours, symbols, and patterns effects their user's ability to understand the hazard warnings and maps, with due emphasis on including all user groups and ensuring no user groups misinterpret the information.

6. Conclusions

In this study, we investigated how the communication of natural hazards (avalanches, floods, landslides, and dangerous weather) works for persons with colour vision deficit, by looking at colours, legends, and maps at the Norwegian national natural hazard portal Varsom.no. Furthermore, we investigated how a new version of ATES could be communicated using maps. To carry out the testing, we developed several designs of colour palettes, legends, and maps. By using two web-based surveys we found that what works for colour-deficient participants also works for participants who have full colour vision.

More specifically, the Meteoalarm colour palette is best (and that of Varsom worst) for communicating danger levels, an additional visual aid is needed for users with colour vision deficiency (colour is not enough if using traffic light concepts), and the ski run colour palette (green, blue, red and red with black hatching) is best for communicating ATES classes.

All in all, the three perspectives on how to improve the communication of natural hazards warnings complement each other. The insight gained from this study adds to the basis for decision making on how to improve the warnings for persons with colour vision deficiency, as well as those with full colour vision.

The findings are also relevant to communication of other hazards and warnings, as well as communicating results from science in general. We investigated how to explicitly include persons with colour vision deficiency, when communicating risk in earth sciences, engineering, geography, and social sciences. Our research has an applied and multi-disciplinary perspective, and a particular focus on reducing the impact of disasters by effectively communicating with the users of natural hazard warnings as well as avalanche exposure maps. We believe this article will contribute to the exchange of ideas and transfer of knowledge on disaster research, mitigation, adaptation, prevention, and risk reduction at all geographical scales.

Significant resources are used to deliver high quality products from warning and educational servicers around the world. This article highlights the importance of not compromising great products by suboptimal visual communication, using colours and symbols that are difficult to recognize, separate or respond to. It also highlights the need to cater for persons with colour vision deficiency by developing common practices, standards, that use colours and supplementary information such as annotation and numbers, in the best possible manner.

Data availability

All material necessary to replicate these results (forms and data) can be found on OSF.

Author contributions

All authors were involved in the conceptualisation of survey 1 or 2, or both, and writing of the manuscript. CO designed and analysed data from survey 1, while RE designed and did the initial analysis of the data from survey 2. GP did the statistical analysis of all data. JH and AH were involved in the design and analysis of data from survey 2.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

The colours (RGB-values) listed in Tables A1 and A2 were used in this study.

Table A1
Traffic light colour codes for the different versions used in survey 1 (version 1–4) and 2 (version 1–4). Versions 1.1 and 2.3 are equal (Varsom colours), while version 2.2 is an adjusted version of version 1.4.

Category	Survey 1 colour palette versions				Survey 2 colour palette versions			
	1.1 Varsom	1.2 New	1.3 New	1.4 New	2.1 EADS	2.2 New	2.3 Varsom	2.4 Meteoalarm
4	227,17,27	188,0,14	188,0,14	188,0,14	254,0,0	209,21,26	227,17,27	254,1,4
3	243,96,20	248,183,41	248,183,41	243,96,0	254,152,0	244,158,48	243,96,20	254,203,50
2	255,205,51	255,236,80	255,236,80	252,239,108	255,255,0	255,236,82	255,205,51	255,255,1
1	119,177,6	0,169,78	0,169,78	158,220,73	186,211,124	46,151,81	119,177,6	41,214,96

Table A2
ATES map colour codes (RGB values) used for ATES classes in the different map versions used in survey 2. The ATES maps were overlaid topographic map using a 50% transparency setting.

ATES classes	Map versions					
	1	2	3	4	5	6
4	236,28,36	215,25,28 with black diagonal lines on top	208,28,139 with black lines (0,0,0) in diagonal	44,123,182 with black diagonal lines on top	254,0,0	123,50,148 with black diagonal lines on top
3	0,0,0	215,25,28	208,28,139	44,123,182	254,152,0	123,50,148
2	66,72,194	44,123,182	241,182,218	171,217,233	255,255,0	194,165,207
1	62,160,49	156,161,145	184,225,134	184,225,134	186,211,124	166,219,160

Opening for feedback in surveys is often useful both for the users (they are provided a communication channel for influencing future changes), and product owner and developers (they get new ideas and feedback on the products). Respondents are often users or potential users and contribute valuable knowledge, experience, and ideas on behalf of the user community. Table A3 provides a selection of feedbacks received during survey 2.

Table A3
Selected feedback from survey 2. Feedback from respondents with CVD is shown in italics.

Theme	Feedback

(*continued on next page*)

Table A3 (*continued*)

Theme	Feedback
Class 4 Extreme	• *Black and cross hatching is supported as a good visual aid by several respondents.* • I think the black lines indicating the riskiest terrain is very effective. • I like red and black for high and extreme. • I like the cross hatching on Extreme a lot. • It would be more intuitive for me if black = extreme and red = complex.
Class 1 Simple	• *Use yellow instead of green. However, hashing out one of the colours helps me greatly!* • *I liked Map A but any Green has too many connotations of "G'' for me. Would Map A but with a bright Yellow replacing Green work. Removes the chance of Green being seen as fundamentally too safe and different colour schemes from the snow conditions hazard scale?*
Class 0	• Make non-avalanche white • Don't neglect the new 0 class. This will be a great indicator of good destinations for high risk days, beginners, and solo outings. Make sure it is easily distinguished from unmapped areas. • ATES-0 is long overdue. I am very excited to see this product go live. ATES-0 will be very important for snowshoers and uninitiated recreationalists who want to avoid avalanche hazard completely as AST courses and requirements to have travel companions can present a significant bar of entry. • I also think it is a shame that non avalanche terrain colours was not added to the survey as they will need to be a part of the scale in the end. The pallet that instantly stands out to me as being favourable for this would be Non–- Light Green, Simple – Yellow, Challenging – Orange, Complex – Red, Extreme–- Back (or maroon).
Two more classes	• *Love that there will be 5 ATES/KAST terrain types, helps much more clearly define zones more appropriately!* • *I am not sure how I would treat complex or extreme terrain differently from a guiding perspective not sure of the benefit of this distinction … why do we need both?* • *The challenge with having more categories delineated with more colours potentially leads to being visually overwhelmed by what you se'.* • *I'm not sure if the added sections will contribute much to risk management as the difference between complex and the new level four is not large. If t'ere's hazar' it's not a great idea either wa'. I'd say the same about the new level zero. I' it's easy to avoid terrain then effectively t'ere's no risk unless you jump right in. Would this change decision making and planning?* • *To improve public information about travel and experience it is important to keep and use a simple or school version with the 3 first classes. So that the class 0 and 4 is more an advanced or map show version.* • I am glad non avalanche is being added, I am not convinced extreme terrain needs to be separated from Complex. • Adding non avalanche terrain is a great idea. Adding extreme is unnecessary and adds complexity to a map that is already difficult to read. • I think this is a great idea! Only 3 classes in ATES has always been annoying for me.
Hatching	• *I find the different hatching aids interprη2tion and printing in black and white.* • *I like the hatched concept as it is easier to see this over the contours of a topomap.* • *A problem with shaded colours is seeing the height curves.* • I also like the idea of cross hatching for extreme terrain rather than a solid color. • I like the schemes with the texture added to extreme terrain (ie lines or stripes) to make this terrain stand out, however I think this may be misinterpreted as closed terrain. • I like when "extreme terrain" is marked with diagonal black lines, and avoid having only the "strongest" color of the scale in order to make understand people that "complex terrain" is the most exposed taking into account avalanches, because "extreme terrain" is more dangerous but not usual as ski terrain.
ATES vs KAST	• *In Norway, or at Varsom the least, avalanche terrain is synonymous with start or runout zones. This is also visualized on maps in the Varsom Regobs app, where terrain steeper than 30° (potential start zones) is displayed in yellow-red colours and modelled runout zones are shown in three shades of blue. Some Norwegian respondents pointed out that ATES with its avalanche terrain exposure classes may be confused with the avalanche terrain classes start zones and runout zones.*
Traffic light colours	• *Separating the concept from the Backcountry Avalanche Advisory is important (this uses similar colours so can be confusing …).* • I believe most people intuitively know that green means good and red mean bad, the colour scale should reflect that. • I think ATES should use another color scale than the Avalanche danger color scale, for avoiding misunderstandings.
Versions A and B	• *The colour scale used to distinguish different levels of challenge in terrain in the ski area could be useful for intuitiveness: green - simple– blue - challenging–, red - complex, black – extreme. (I like the hatched concept as it is easier to see this over the contours of a topomap). Switch red and–black - having red for extreme and black for complex does not make sense to me.* • Many people who venture into avalanche terrain are of course skiers or snowborders. Many of those will have spent a lot of time in ski lift served areas. They will therefore be familiar with the color coding system for ski slopes, ranging from green to black. People with this background will most likely interpret black as more severe and/or extreme than red.
Other	• I think green and blue are colours associated with wood and water in maps. I would therefore not recommended using this in your new maps. • I think using blue on a map to denote anything but water is confusing and should be avoided. • If maps are displayed at trailheads (as it is at some popular sites in BC), an indication that the map does not display snow conditions/risk would be good. • I think a simple diagram in addition to the written description of each rating could be very useful and helpful for educational purposes. • My eye seemed to work best with only 3 colour options, with any more colours it becomes too cluttered, so I think separating out the terrain classes into a 3-colour system is the most visually easy to distinguish. And then micro-managing the higher terrain classes with dashes or something within the same colour? Love the new visuals! • Several participants pointed out that they rather liked the avalanche terrain maps shown in Varsom Regobs and Fatmap.

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