Design and Evaluation of a Wearable AR System for Sharing Personalized Content on Ski Resort Maps

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ABSTRACT
Winter sports like skiing and snowboarding are often group activities. Groups of skiers and snowboarders traditionally use paper maps or board-mounted larger-scale maps near ski lifts to aid decision making: which slope to take next, where to have lunch, or what hazards to avoid when going off-piste. To enrich those static maps with personal content (e.g., pictures, prior routes taken, or hazards encountered), we developed SkiAR – a wearable augmented reality system that allows groups of skiers and snowboarders to share such content on a printed panoramic resort map. The contribution of our work is twofold: (1) we developed a system that offers a novel way to review and share personal content in situ while on the slope using a resort map; (2) we report on the results from a qualitative analysis of two user studies to inform the design and validate the usability and perceived usefulness of our prototype.

Author Keywords
Information sharing; skiing; augmented reality system; wearables; qualitative data analysis; user study.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
Skiing and snowboarding are highly social activities, attracting millions to the mountains every year [27]. With the advent of portable GPS tracking devices and wearable sensors, it became possible to record one's own performance data on the slope and share it with others – to enrich an evening conversation or spice up a friendly competition while on the slope. Such captured data can also help with the many decisions a group of skiers or snowboarders faces throughout a day: which piste to take next, what area to avoid when going off-piste, or how to catch up with friends for lunch or après-ski. Traditionally, paper maps or larger-scale board maps mounted along the slopes have supported skiers and snowboarders in these decisions by offering a basic navigational overview. However, such maps do not support the sharing of any personal content (e.g., recorded GPS tracks and pictures taken) or customized context (e.g., relevant points of interests and hazards) that are often the basis for making such decisions. A plethora of dedicated ski apps available in today's app stores do support such sharing, yet interaction with a smartphone is often inconvenient on the slope due to harsh environmental conditions and/or cumbersome gear (e.g., gloves) [8]. Based on design requirements that we extracted from prior work [5, 7, 28], we developed SkiAR, a wearable augmented reality (AR) system that supports groups of skiers and snowboarders with their on-slope decision making processes. SkiAR offers a novel way to share personal content in situ using wearable AR equipment and a printed resort map. Our prototype consists of an AR application running on a smartphone worn using a head-mounted display (HMD) holder, a wrist-worn input device (smartwatch) to control presentation and sharing, and a server that provides content synchronization between multiple devices (see Figure 1). The prototype uses a custom designed algorithm that maps location-tagged personal content (in the form of pictures, tracks, points of interest, hazards) onto corresponding coordinates of a traditional panoramic map of a ski resort (see Figure 4). To the best of our knowledge there is no similar system in the context of outdoor mountain sports.

We administered two initial user studies with a goal to evaluate the usability and perceived usefulness of the prototype with an experienced group of skiers and snowboarders. We first conducted a lab study with seven pairs (i.e., 14 participants) of winter enthusiasts to get early feedback on its potential acceptance. Next, we conducted a field study with 12 participants in an alpine resort to evaluate the usefulness and usability of the prototype. Both studies also included an open-ended discussion session that identified factors that may improve the design of the system and its potential use beyond winter sports. This paper describes the design and architecture of SkiAR, reports on the results of our two user studies, discusses general considerations for the design of AR systems to support group decision-making on the slopes, and outlines avenues for further research.

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RELATED WORK

Augmented Reality Systems

AR technologies provide a way to enhance our senses and perception of the real world by providing contextually relevant information about both objects and the environment around us. With contemporary AR technologies, finding additional information about an object of interest is as simple as pointing a mobile phone's camera to it and watching the screen. Van Krevelen [12] provides a comprehensive overview of applications in the space, explicitly discussing personal assistance, collaboration, and navigation tasks – all of which our system supports. Olsson et al. [17] conducted a study covering five day-to-day scenarios, from workout sessions to shopping experiences, where an AR-enabled smartphone could assist to run those routine activities. While their study featured a single device perspective, we explicitly envision collaborative multi-device usage. Langlotz et al. [13] introduced the so-called "AR 2.0" concept, where users can create and share user-generated content. We build on this work by adopting social AR principles and incorporating authoring capabilities into our system. Billinghurst and Kato [1], in their study of collaborative augmented reality, discovered that interactions with an AR interface are often similar to natural face-to-face interaction in object-centered collaborations. Moreover, they discovered that an AR interface does not separate a communication space from a task space, which is crucial for decision-making tasks on the slope. The SkiAR system leverages these findings and uses a printed resort map as a physical reference to overlay personal information gathered from a user's smartphone. This should help facilitate conversation around shared content and support in situ decision making.

Augmented Maps

Schall et al. [23] surveyed a large body of work in the area of augmented maps. Most notably, previous research has explored the creation of interactive printed maps using RFID [19], fixed [20] and portable [9] projection technologies. Schmalstieg and Reitmayr [24] used a tangible input device to indicate a precise location on a map and show additional information about it on a PDA. All of these setups require infrastructural interventions, such as setting up a stationary projection system or mounting sensors around a map. Our system uses markerless image tracking and hence does not require any modifications of the physical space. Schöning et al. [26] employed a *magic-lens* approach to interact with personalized content on a poster-size city map where a user is required to hold a phone in mid-air. In an outdoor scenario such as skiing, however, with its often harsh usage conditions, we instead use a head-worn display for information delivery. Morrison et al. [16] found that AR maps can encourage discussion, negotiation, and problem-solving, and emphasized that the main potential of such systems is in collaborative usage. We have accommodated the various design observations from their research, but instead of following their gamification approach we explore actual decision-making tasks while on the slope. Inspired by a study by Rohs et al. [22] that compared 2D digital map navigation with an interface based on visual tracking, we employ a tracking interaction technique also in our system. In contrast to their study, however, our goal is not to compare different interaction techniques, but rather to probe possible scenarios where our system might be useful. Dunlop et al. [5] discussed the importance of visualizing personalized ski data using familiar resort maps, rather than generic online maps (e.g., Google Maps). Following their findings, we incorporated the use of traditional panoramic resort maps.

Technology to Support Skiing Activities

Previous research has looked at the skiing domain from a mostly technical perspective. Researchers described the emerging connectivity in the mountains [18] or built wearable computers to support on-slope communication [28] and navigation [25]. Jambon and Meillon [11] conducted an in situ evaluation of an "E-skiing service" to support the skiing experience, and outlined a number of challenges while conducting experiments outdoors that involve complex hardware and software setups. We decided to use popular off-the-shelf devices that share a common software ecosystem, in our case iOS (using an iPhone 6 and an Apple Watch), in order to approximate a future gadget for winter enthusiasts. Several companies recently announced wearable devices to enhance the skiing and snowboarding experience. To mention a few: *Forcite Alpine* (www.forcite.com.au) attempts to redesign the ski helmet by embedding a radio transceiver and a high-definition camera into it. *RideOn* (www.rideonvision.com) eventually plans to incorporate a see-through AR display into ski goggles to support navigation and to facilitate play-on-piste. As of August 2016, however, no actual product has been launched. The *Recon Instruments* (www.reconinstruments.com) *Snow2 MOD live remote* is aimed at solving the interaction problem with personal devices hidden in jacket pockets by placing a glove-compatible controller on a wrist above a ski jacket, featuring a remote controller that has 6 stand-out buttons that can be easily pressed through a ski glove. These commercial products, prototypes, and visions help illustrate the overall potential of our system.

SKIAR SYSTEM

Design Requirements

Ski goggles, a helmet, and gloves are typical attributes of any skiwear. We built our prototype with a vision of using ski goggles as an output display to provide additional information to skiers and snowboarders. While today's dedicated winter sport apps [3] already enable outdoor enthusiasts to inquire current slope conditions, locate and communicate with friends on the slope, and log comprehensive field performance data, such devices are far from ideal when it comes to on-slope use [8]. We thus opted for a wrist-worn controller in our setup in order to eliminate the trouble of having to take a phone out of a pocket. Our SkiAR prototype approximates future technologies (as head-mounted optical see-through displays for active sports and "gloves-friendly" input interfaces) with the help of a conventional smartphone that is mounted in a head-worn phone holder and a smartwatch for control. Note that skiers

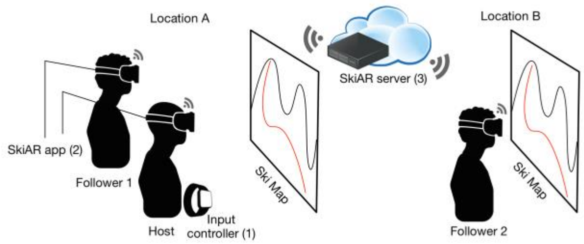

Figure 1: SkiAR system overview. Generic HMD and watch images CC BY 3.0 Boudewijn Mijnlieff and Sherrinford from Noun Project.

and snowboarders often wear non-transparent, reflective goggles that prevent direct eye contact during social encounters and, due to the peculiarities of the design, usually limit their peripheral perception. Therefore, our prototypical setup approximates a realistic deployment quite well, which allows us to evaluate the perceived usefulness of presenting map augmentations and to examine how interaction and collaboration can be facilitated in decision-making scenario in front of a shared physical map. While existing in-goggle displays (e.g., Recon Snow2) simply offer an extra screen that can be used for notification purposes, our video see-through interface not only offers a more immersive experience, but also resembles more closely envisioned AR products such as the RideOn goggles with its optical see-through setup. We particularly have chosen video see-through AR platform for our first prototype, not only because of the wider field of view in contrast to modern state of the art optical see-through commercial devices (i.e. Microsoft Hololens) [29], but also due to the brighter display capabilities, which is critical for outdoors usage.

The sharing of personal and contextual information among members of a winter sports group is not only crucial for safety, but also often one of the key ingredients to a positive skiing experience [7]. An empirical study by Fedosov and Langheinrich [7] with a group of backcountry skiers showed that the most important information they shared within a group were reference information necessary for descent, up-to-date location of skier in a group and captured photos and videos. Consequently, our first prototype supports sharing four types of GPS-enriched content: pictures, tracks, points of interests (POIs), and hazards. However, our study participants provided us with further suggestions for content that the system could support in order to offer contextual aid while on the slope – see the Results section for details.

System Overview

The SkiAR system consists of: (1) an input device (smartwatch) that offers a simple selection interface; (2) an output device (head-mounted mobile phone) running a SkiAR application that overlays user-selected content onto familiar resort maps, and (3) a SkiAR server that handles synchronization of content between multiple users of the system in real time. Figure 1 shows the system configuration at a glance. Figures 5-6 show how the setup is worn by a user. A detailed system description can be found in [6].

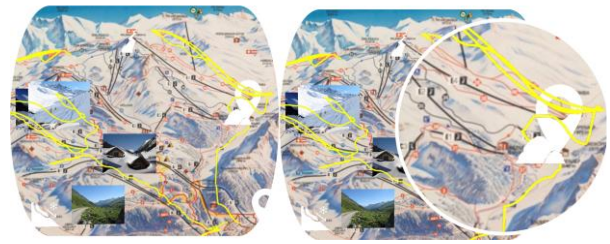

Figure 2: AR content delivered to HMD with a close-up view (right)

The SkiAR system enables skiers and snowboarders to add and review personalized content in the form of pictures taken previously, tracks run, hazards and POIs encountered, as well as to share these details among group members using a familiar resort map. The system supports two modes: personal and sharing. In *personal* mode, a user can review personal information. This information is only visible within the user's AR goggles. The *sharing* mode supports sharing such information within a group. In the current prototype, groups need to be setup ahead of time (i.e., before starting to ski) as this still requires a number of manual setup steps, such as establishing a shared data storage for the group (e.g., on a WebDav share). Also, the prototype does not yet support concurrent information sharing – at any point, only one user can be the "host" of a sharing session, while all other group members are simply "followers" (see Figure 1). We acknowledge that in a real decision-making scenario, roles in a group may change frequently, depending on the situation at hand. Therefore, in our system any group member can request and subsequently take over the host role and start sharing their content with others. Future prototypes will investigate both ad-hoc group forming as well as concurrent content sharing.

The SkiAR server is implemented using *Node.js*. It offers basic group management and controls individual sharing sessions. Our prototype requires that all skiers have Internet connectivity throughout the ski resort. In principle, followers do not have to be co-located with the host (see Figure 1).

SkiAR App and Input-Output Interface

The SkiAR app uses printed maps of a ski resort as a tracking reference to overlay user's virtual content on top of it. We use the Metaio SDK for iOS (www.metaio.com) to support markerless tracking on the resort maps. To allow for the use of a commodity smartphone in an HMD-mount (e.g., such as Dive 5, see www.durovis.com), SkiAR renders two screens next to each other (see Figure 2). The iPhone 6 that we use in our prototype provides a resolution of 750x667 pixels per eye at a refresh rate of 60 fps. The horizontal field of view (FOV) of our assembled setup is similar to other wide-FOV AR systems [29]: 60 degrees for the phone itself and 90 degrees for the HMD headset that we used. The actual frame rate and screen resolution are controlled by the Metaio SDK. Figure 2 illustrates the system's current user interface as seen through a HMD. The SkiAR app positions photos, tracks, hazards, and POIs at their corresponding physical locations

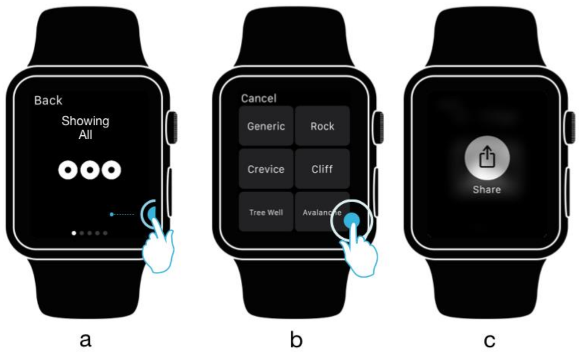

Figure 3: SkiAR input interface on a smartwatch. Generic watch image CC BY 3.0 m from Noun Project.

on the ski map. Photos and tracks are imported directly from a user's smartphone (e.g., photo gallery, workout tracking app). The placement of these items is based on their embedded latitude and longitude information (e.g., EXIF information for pictures or GPS waypoints for tracks).

Our SkiAR prototype uses a smartwatch as the input device. The watch is wirelessly connected to a smartphone in host mode and runs a companion app. Figure 3 shows the watch user interface in SkiAR. The user can control information presentation using left and right swiping gestures. Figure 3a corresponds to the information presented to the user on Figure 2, where all available virtual objects can be seen in a single view. However, users can filter and display only one category of objects at a time (e.g., only "Hazards", or only "Photos") by using a left swipe gesture. Photos are presented in a thumbnail view or in larger scale upon a user's request (a tap on the watch). Additionally, as shown in Figure 3b, it is possible to add new objects to the system using the watch interface (e.g., when encountering hazards such as tree wells, avalanches, cliffs, uncovered rocks, or crevices). In this mode, the system reads the current GPS position of a skier and registers a new hazard at this position. Finally, the host of a session can share any content category with other skiers in the group by applying a touch gesture while in the corresponding category and pressing "Share" (Figure 3c). The SkiAR system will then update the corresponding information for all followers automatically. The currently selected object – a POI, an image, a track, or a hazard – will be highlighted in red and will become visible for all users (see the ski map illustration in Figure 1).

In order to visualize personalized content on a panoramic resort map at the appropriate location, we designed a conversion algorithm for our system. The goal of our algorithm is to estimate the position of a point on a panoramic map given its GPS-coordinates. For efficiency reasons, we divide our algorithm into two phases. The first phase (preprocessing) consists of manually identifying correspondence points in the two maps and constructing the necessary data structures. Showing the topographical map

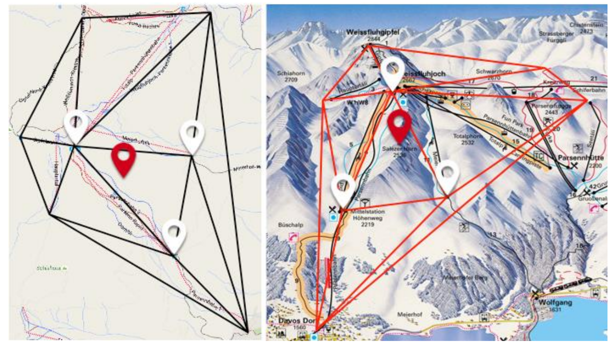

Figure 4: Example of triangulation of points in the topological map (left) and panoramic map (right)

(e.g., Google Maps) and the panoramic map side by side, we mark[1] easily identifiable points such as the beginning and end of slopes/ lifts, the location of restaurants, etc., in both maps (see the white pins in Figure 4). The more such corresponding points one identifies, the better the fit will be. In our experiments, about 20 points were usually sufficient to achieve a good fit.

The second phase is the actual computation of the position of a given point in the panoramic map. For this, the algorithm uses the Delaunay triangulation [4] on the points in the topographical map and carries the connectivity of this triangulation over to the panoramic map. In this way if three points are connected in the topographic map, the corresponding three points will be also connected in the panoramic map (Figure 4). Once this connectivity has been computed, we can directly translate between GPS coordinates and "map coordinates", e.g., locating an arbitrary POI (see the red pin on Figure 4) and subsequently drawing a GPS trace onto the resort map (see yellow tracks on Figure 2).

STUDY DESIGN

The aim of our prototype is to aid decision-making and in situ information sharing among skiers or snowboarders in a group. To evaluate the system, we set the following three research questions:

- **Perceived usefulness and purpose:** What application usage scenarios do snowboarders and skiers envision for such a system?
- **Content sharing:** What information is most useful to share in a group when making decisions where to go next?
- **System usability:** Is the proposed system and interface usable for sharing content on the slope?

To answer these questions, we conducted two initial user studies: (1) we performed an in-depth evaluation of the system with seven groups of skiers in the lab; (2) then, we conducted a field experiment to evaluate the prototype outdoors in a ski resort in the Alps with 12 participants. Both studies were conducted in front of a poster-size ski resort

[1] We developed a simple tool for this.

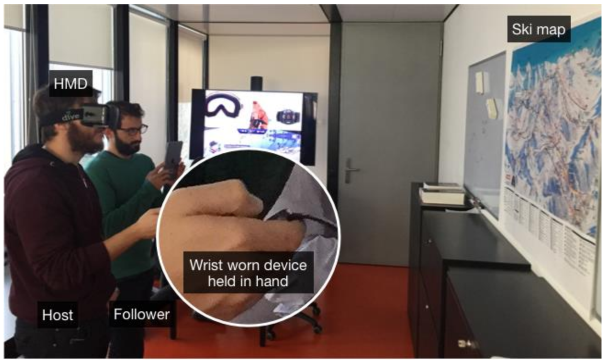

Figure 5: The laboratory setup of the SkiAR system

Figure 6: The field experiment setup

map: indoors for the lab experiment, and outdoors for the field study. These maps were chosen as a shared physical frame of reference because the space around them is highly social and enables collaboration during decision making between skiers and snowboarders in a group (e.g., see the setting shown in Figure 6).

Lab experiment

We first performed the controlled laboratory experiment. We recruited seven pairs of skiers with various levels of experience through university mailing lists and personal contacts. Two participants considered themselves beginners, six intermediates, five advanced, and one expert. The age of our 14 participants ranged from 22 to 34 years, the average age was 28 years (SD = 4.1), 3 of them were female. Participants were recruited in pairs to approximate actual in situ group making decision while on the slope.

Study Setup

A session with a pair of participants took on average 50-60 minutes. First, we briefed participants on the goals of the study and asked them to sign a consent form. Two researchers conducted the study: one administered the study while the other was observing and taking notes. The study consisted of five stages:

1. Pre-study demographics questionnaire to assess participants experience with winter sports, and their familiarity with traditional ski resort maps.
2. Demonstration of the SkiAR system in front of a poster-sized ski map. A researcher demonstrates the system, followed by a short trial session where participants are able to try the prototype themselves.
3. Participants work through two scenarios that require decision making in front of the map. Each participant once acts as a host (sharing pre-defined content) and once as a follower (reviewing content and supporting conversation).
4. Post-study questionnaire to evaluate the usability and usefulness of the SkiAR system.
5. Semi-structured interview to reflect on the experience with the prototype.

Scenarios

In the first scenario, the first participant acts as host and the second as a follower. Participants are asked to envision the end of a ski day, in which the host was skiing while the follower was not. The task of the host is to describe his/her ski day through reviewing and sharing pre-defined virtual content (pictures, POIs, tracks, hazards) on the map in order to plan the next day together with the follower. Since we had only one head-mounted gear and smartwatch pair-unit (which was used by the host), the follower had to use a tablet computer during the study session (see Figure 5).

In the second scenario, participants switched roles. This time, we asked them to envision a lunch break, when both participants had been skiing together since morning. The virtual content that was available to augment the map was different from the first scenario. In this scenario, the two participants should decide on the safest route to take in the afternoon, based on various hazards the host encountered along his/her respective tracks from the morning runs. In both scenarios, the host was asked to explicitly share (Figure 3c) pictures, hazards, tracks, and points of interests with the follower, so the follower could see them on the map.

Field Study

For the field experiment we recruited twelve skiers and snowboarders with various levels of experience during a week-long winter seminar for PhD students at a ski resort in the Austrian Alps. Participants were recruited using snowball sampling. Two participants considered themselves beginners, three intermediates, two advanced, and five experts. The age of our 12 participants ranged from 25 to 36 years, the average age was 28.9 years (SD = 3.25), two of them were female.

Study Setup

Every day throughout a week one researcher was inviting one or two of the participants to ski together during a morning or an afternoon and, subsequently, meet for a study session in front of a board-size map at the resort. During the ski run, participants and the researcher were taking pictures together, recording tracks, and adding few hazards encountered on the way. We manually added a number of fixed POIs for all participants before the study to ensure completeness of a dataset with respect to virtual content

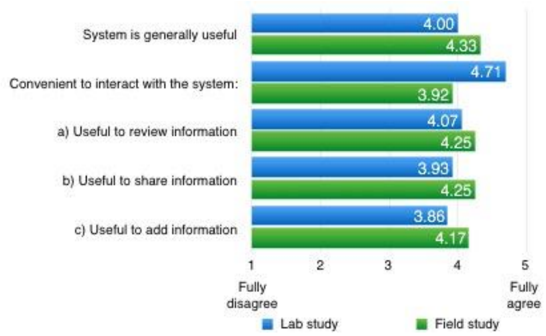

Figure 7: Perceived usefulness of the SkiAR system (Lab Study N=14, Field Study N=12)

types. On four occasions it was not possible to arrange a ski run with participants – in these cases, the researcher met them directly for the study session. The actual study session in front of the map took on average 15-30 minutes. First, we briefed the participant (on two occasions we had a pair) on the goal of the study, requested a consent and then asked to try the prototype that showed (localized) sample content previously entered into the system by the researchers. Two researchers conducted the study: one administered the study while the other was observing, taking notes and pictures.

Sessions

In contrast to the lab study, here we did not have any pre-defined scenarios, but rather asked participants to decide where to go next, given the current state of the content added to the system earlier. To reduce time of the experiment, participants were only required to wear the head-mounted smartphone and review the content (see Figure 6) – a researcher was using the wrist-worn controller to drive the discussion. In summary, the study consisted of 4 stages:

1. Collecting content (pictures, tracks, hazards) while skiing together with one researcher.
2. While in front of the map participants were asked to reflect on personalized content and decide where to go next. Participants were "followers", while the researcher acted as "a host". A few participants also wanted to (and were allowed to) try the host mode.
3. Post-study questionnaire to evaluate usability and usefulness of the SkiAR system.
4. Semi-structured interview to reflect on the experience with a prototype in a real world setting. Demographic information was also collected at this stage.

Data Collection and Analysis

In both studies we asked participants to complete a post-study questionnaire, in which they needed to indicate their level of agreement on several statements regarding the usefulness of the SkiAR system, using a 5-point Likert scale (see Figure 7). Additionally, immediately after our participants experienced the prototype, we administered a System Usability Scale (SUS) questionnaire [2] with ten questions, also using a 5-point Likert scale. The SUS questionnaire is an established method in HCI to evaluate the usability of a system. SUS scores are between 0 to 100 points; systems that score more than 68 are considered usable above average.

The last part of both studies was a semi-structured interview. The goal of this part was to unfold the user experience with the prototype, and to collect suggestions for its design. We recorded all interviews using a voice recorder, then transcribed recordings verbatim. Additionally, the researchers took detailed notes of each interview. To analyze this data, we followed an iterative process, going back and forth between the data, the researchers' notes, and the emerging structure of empirical categories, which we developed through recurrent reading of the material [14]. To draw out common factors of the system, we adopted a contextual design methodology and constructed an affinity wall [10]. This technique helped us to define ideas for new content and applications of the SkiAR system, as well as inform the interaction design to better meet skiers' and snowboarders' needs. In addition to discussing each theme, we also collected participants' quotes to support the topics that emerged for each category.

RESULTS

Perceived Usefulness and Purpose of the System

Participants from both studies regarded the SkiAR system as generally useful to have during skiing or snowboarding (see Figure 7). *"It is a nice idea to have finally some interactive maps where I can retrieve useful information or see where others and myself have been skiing."* (P26, similarly P15). Figure 7 shows that participants from the field study generally gave higher scores (higher perceived usefulness for the system in general, as well as for each individual functionality – review, share, and add content). We speculate that this may be because the field study participants were in a more realistic decision-making setting.

We examined if there were any significant differences in perceived usefulness scores between lab and field settings. Shapiro Wilk Tests of normality did not confirm the assumption of normality for our data set. Non-parametric Mann-Whitney U tests revealed that participants in the lab thought that the system was significantly more convenient to interact with (Mdn = 5) than participants thought it was in the field (Mdn = 4: U = 34, $p < .05$). Indeed, as we can see from Figure 7, participants of the lab study especially appreciated the convenience that the system provides when watching the overlaid information through the goggles and operating it through a wrist-mounted controller. *"Interaction with the watch is the way to go [on the piste]"* (P5, similarly P6, P11, P12). However, in outdoor settings, interaction convenience was seen more critical: *"There might be something that you want to input to the system while on the slope, you don't want to stop - but that would be more infrequent. But for more frequent sharing situations when you stop, wrist-based or head-mounted [interactions] are fine"* (P17).

In the post-study questionnaire, participants indicated that hazards were the most useful content that influenced decision making, followed by tracks and points of interest. *"Hazards is crucial for off-piste safety"* (P9, also P12, P14, P15, P17-19) Pictures were regarded the least useful. Participants also indicated that they are willing to share hazards and POIs publicly. *"Adding hazard is useful for other skiers"* (P8, also P5) Sharing of tracks and pictures taken are usually limited within a group. *"It is useful to share pictures, say, in the group of 10, no need to approach everyone individually and need to remember where this one was taken"* (P3 also P17).

During a semi-structured discussion session at the end of each session, participants provided also insights about scenarios where the SkiAR system could be used. As anticipated, participants valued the system's ability to **support decision making** while on the slope: *"I usually get confused with the slopes you already took and the ones you haven't, with the prototype you immediately see where we have been."* (P21, also P7, P15, P26). Decision-making is aided through **quick review and share** actions of personal content with group members. SkiAR alleviates the burden of reaching out into a pocket for a smartphone to show some additional information to another member of a group. *"It is easy to share with the group, also quite quick. I don't need to pull out my phone"* (P3, also P4). Furthermore, the app appealed to skiers and snowboarders when getting lost or split from a group to **coordinate with others**: *"Useful to share with a group. When I'm lost I can send my position that we can meet at some restaurant. Great way to catch up with others"* (P9 also P24). Additionally, users saw value in **reflecting on personal and group activity** through the app after a ski day. *"I see reviewing my content with friends at home or in a hotel using the app"* (P14). Few participants mentioned that the SkiAR app **enables storytelling**: *"Pictures and videos better communicate a skiing experience, tell a story"* (P14 similarly P21). Furthermore, participants said that the app can **provide better awareness** about the variety of places available around a resort (e.g., where to meet for a lunch), or for pointing out dangerous spots on the slope. *"I think it is really nice to have an overview while skiing, especially in bigger ski resorts"* (P24 also P11, P17). Finally, users mentioned that the app can **facilitate content mediated interaction** with other skiers, without having to use verbal channels. *"App is great for reducing shouting on the slope. If I got lost, I'd like to use this [app] to know where my peers went, so I do not need to worry [about] taking wrong turn ... just because of sharing content with a group puts everyone on the same page."* (P3). One participant mentioned that the SkiAR could provide **connectedness** to the group members through shared content "*if it is like 20 people going, it could create this feeling of connectedness with the whole group using this prototype*" (P17). Participants mentioned daily **journaling** through sharing with remote friends as a useful application, which can serve not only as a storage of content (e.g. photo album) but also facilitate **ideation**. *"I think it is useful when you can store [content]. Then you could see where you had been last year, ...you can also give some recommendations and exchange ideas with friends"* (P25, also P18, P26).

Content Sharing

Just as in the questionnaire, interview participants found hazards to be the most important content category that they would like to review and share in situ with other skiers, even beyond a private group, especially in an unfamiliar ski area. *"I only go off slopes in the skiing areas I know very well. But for example here, I would not know where is safe to ski, that would be valuable for me to use this system"* (P19). POIs and tracks were also found useful during the day. Pictures, on the other hand, were preferably shared and reviewed with the group when a ski day was over.

Additionally, participants expressed wishes for new content that SkiAR should support. They liked to know about the current **location and a status of skiers within a group**. *"Once I went to ski in a forest and got stuck under a tree, but they [brother and sister] were on the piste. I was not able to communicate to them. It would be cool that app can notify about your location and location of others"* (P4 also P15, P26). One of the most requested detail is **waiting times at a ski lift** that can influence the decision which piste to choose next, as well as contribute to traffic efficiency at a resort. *"I'd like to know that information in advance, and I would of take another one that was not that crowded. Today it would save me 30 min."* (P19 similarly P14, P18, P26). Furthermore, a ski resort operator could provide an assessment how crowded would be at a location throughout a day based on the queue data at a lift. *"Given the frequency how people scan their badges at the station or using a camera there you can give a very good prediction how crowed area is"* (P19 also P26). Detailed **contextual information** related to meteorological conditions at a resort (e.g. weather, visibility) and on a particular piste (e.g. snow conditions, speed of wind) were also regarded as highly relevant to make a decision. *"I'd appreciate to get information about snow quality and conditions at the given time, also those red or green lights to show whether piste is open or closed"* (P20 also P1, P21, P24). Few participants also wanted to attach personal performance data to a piste (e.g. best time, top speed, number of falls) to spice up a competition among friends and beyond. **Up-to-date reference information** (e.g. deals for daily menu at a restaurant, discounts on rental equipment, last bus schedule) was named as another factor to consider when planning the next run. *"I'd like to see POIs with offers – 'cheap beer'. I would definitely go there"* (P5 also P24, P26). Participants also mentioned videos and time-estimates to complete the run as potentially interesting content items to include.

An interesting discussion revolved around **limited and public sharing**. Participants were willing to share informative contextual details such as hazards, POIs, queues at lifts, weather information, as well as anonymized statistics about personal runs. However, locations and pictures were preferably shared only within private groups. Few participants were concerned about the quality of publicly shared content, though we found a need to **maintain and filter** public crowd-sourced content. *"[seeing] duplicates of* *the same pictures on the map would not be that cool"* (P9). Adding another stakeholder to the system, e.g., a resort owner, could perhaps ensure the continued relevancy of critical contextual information like hazards. Since resort-organized ski patrols usually prepare and maintain slopes throughout the day, a system like SkiAR could benefit from their content input. *"Resort should take care of reviewing and updating that kind of information [hazards]"* (P5).

Usability Evaluation

Finally, we wanted to evaluate whether the system is usable for sharing content. After the decision-making scenarios we asked our participants to evaluate the system using a SUS questionnaire. Primarily, we were interested in evaluating the head-mounted display setup since it was a more accurate approximation of the envisioned high-tech skiwear. The SUS of the host system scored 73.75 (SD = 12.46) in the lab and 79.19 (SD = 10.07) in the field study, which suggests that the system we developed is in principle usable above average.

CONSIDERATIONS FOR DESIGN AND FURTHER USAGE

Two further categories emerged during our analysis: (1) suggestions for interaction design to better meet skiers and snowboarders' needs; and (2) envisioned application scenarios of the system beyond winter activities.

Suggestions for Interaction Design

Our field observations showed that board maps are highly social artifacts. As seen in Figure 6, skiers are closely approaching the map, pointing toward it with a pole and discussing where to head next when returning to a slope (often from a lunch break or a lift ride). This fact justifies our choice of supporting poster-size maps as an anchor point in our studies. Given that a physical space around the map is shared among other skiers, designers of systems that uses this space for interactions (i.e. SkiAR) need to account for possible outcomes (e.g. lost visual tracking) during their use (e.g. adopt more robust tracking techniques). This leads us to suggest to designers of such systems that they define a set of **points-of-interaction**, i.e., locations where decisions are being made where to go next, and then optimize the user experience for such encounters. For SkiAR, these points-of-interaction are the poster-sized ski maps near a lift base station or on top of a mountain, as well as pocket-size paper maps that are used while on a lift. *"I may be interested in such a system on the lift ... because there you have more off-time. Once you are hopping on the lift, you always want to see where you can go next"* (P19).

Our current prototype of SkiAR requires explicit sharing of each content category (see Figure 4). To reduce unnecessary interactions with a wristband controller, having an **automatic sharing** technique would be beneficial in a group setting. *"Sharing is the most useful part of the app. I suggest automatic sharing between the rest of the group, while hosting the session"* (P7).

The SkiAR supports a 2-tap input of hazards while on the go by automatically reading the GPS location of a skier and indexing it with a user-selected type of hazard. Participants raised concerns about the implicit expectation in this design to add hazards right after passing them. *"I will input only important points, not everything I have encountered"* (P11). The SkiAR app should thus define a mechanism to insert hazards encountered previously at an **appropriate time** for a skier or snowboarder (e.g. during a ski lift ride). *"People could add hazards later on; they are unlikely to add them on the spot directly"* (P5). **Temporal aspect of interaction** is an important factor to consider for decision-support systems like SkiAR. We observed that interaction with a shared ski map is rather short, people quickly decide where they want to go. On the other hand, during a lift ride people have often more time to spare and discuss their decision. An explicit "follow-up" mechanism could be useful that would allow one to pick up a prior conversation and/or decision taken, e.g., during a lift ride, and show it again at a later time, e.g., a poster-sized map. Additionally, few participants expressed a wish to see **overlaid personal content in the real world** (e.g., a track directly "painted" onto the slope) to support decision making during off-time on a lift or at short breaks while on slope. "*It would be really cool If you can see those hazards or pictures in situ as well because if you ask me now about where the hazards are, I probably remember only a couple.*" (P19). Some participants were also interested in **contextual turn-by-turn navigation** after choosing the POI to go where desired route is calculated automatically (like when driving a vehicle). "*One can say 'Let's just go to a bottom of that cable car!' and everyone gets the navigation aid on his device, to head a bit more on the left or on the right"* (P16 also P26).

One participant expressed a wish to **consult a virtual map** upon request: *"Would be great to pull the map virtually whenever you are on the slope and check it. I don't like to get foldable map from the pocket."* (P14 also P22). Ultimately, being able to **support hand gestures in mid-air** was mentioned a few times in our interviews. One user mentioned finger detection, while selecting a point on the map, another was referring to pinching in/out to zoom for particular place on a map using both hands to get additional information about region of interest. Both ideas are similar to MIT's SixthSense system [15].

Beyond SkiAR

Several study participants suggested applications for our technology in areas beyond winter sports activities. Scuba **diving** has similar equipment requirements as skiing and snowboarding. Divers always wear a mask and many use wrist-worn dive computers to measure depth and dive time for calculating a safe ascent profile. Therefore, virtual augmentations of a shared physical focal point can be explored further in this discipline. Recreational divers often do not have access to voice communication equipment and use non-verbal communication channels instead. The SkiAR concept could be extended to support such requirements. Other **recreational physical activities** such as running, cycling and hiking could also take advantage of our system. Sportspeople often bring measurement devices (e.g., chronometers, GPS trackers, smartwatches) along to track their activity. *"Wristwatch with a haptic feedback could notify about hazards along the route"* (P11). Modern wearable devices for runners and cyclists (e.g., the Recon Jet, see www.reconinstruments.com) provide comprehensive statistics about sport activity in real time. Cyclists and hikers often consult a map during their activity and would benefit from shared information left by fellow sportsmen.

Several participants suggested targeted use of our system for **training** and testing purposes when it comes to the **disaster simulations** like controlling spreading fire or monitoring an area after an avalanche. Emergency management is a promising field to deploy our system given that physical maps are widely used for disaster analysis and support tasks.

Finally, **museums and amusement parks** always provide paper maps and larger-scale poster maps to their visitors to aid navigation within premises. The SkiAR system could provide interactive contextual information and improve navigation during a visit: *"Map of museum could be more interactive, informative with POIs to show different artefacts"* (P12), *"it can show queues at the rides in an amusement park on the map"* (P8).

DISCUSSION

While we received positive feedback about the system from a total of 26 participants, our prototype represents only an initial approximation of a potential future consumer product for skiers and snowboarders. We found that participants highly valued the usefulness of not having to hold a phone or even a paper map in their hands while on the slope. Half of our subjects from our lab study were able to operate the wristband controller without even looking at it. Given that none of them had prior experience using a smartwatch, this suggests that our simple UI and the minimal interaction with the system was the right choice for outdoor winter activities.

Further development of the prototype is required in order to accommodate day-long use of the system. For example, in order to interact with the touch screen of the smartwatch we use as the controller, skiers currently need to take their gloves off. While the choice of using a smartwatch in our prototype allowed us to easily support interaction with augmented content on the map with the set of simple micro interactions (swipes), an improved version of SkiAR would feature a remote control device that supports button-push events while wearing gloves (e.g., the Recon Instruments Snow2 MOD live remote). Similarly, the availability of a sport-tailored optical see-through display technologies (e.g. the RideOn ski goggles) would allow us to fully support the experience that a system such as SkiAR may provide.

Future developments of accurate outdoor tracking systems would also benefit overall SkiAR performance. In particular, using visual tracking technologies outdoors is a known challenge due to different lighting conditions throughout a day [24]. We used a so-called "markerless" tracking technique in our prototype, which requires most of the tracking region (e.g. map) to be visible by phone's camera at once. In our field experiment, our system thus lost track several times as other skiers passed by or stepped in front of the poster-sized map. More robust tracking techniques and algorithms (e.g. point-cloud tracking) could significantly improve the user experience of our system.

While our prototype used a video see-through technology for overlaying virtual content (in contrast to, e.g., the envisioned RideOn commercial product, which should use an optical see-through system), our findings described in sections *Suggestions for Interaction Design* and *Beyond SkiAR* above do not rely on any particular AR technology – and hence in general would benefit designers and developers of various AR systems to support collaborative decision-making on-piste and beyond. Furthermore, our findings related to personal content reviewing and sharing described in sections *Content Sharing* and *Perceived Usefulness and Purpose of the System* above (e.g., what pictures to share, or entering a new POI) can be seen independently from AR and thus in principle also apply to any system, which supports collaborative skiing.

As a limitation of our study, we recognize the lack of concurrent sharing scenarios of digital content in our experiments that may be important in collaborative decision-making. Our lab participants had to assume the roles of a "host" and a "follower", partially due to the architectural peculiarities of our system to handle shared resources, and the fact that we had only one HMD unit at our disposal. Therefore, participants in the lab experiment had to alternate roles in order to present content. In principle, the current SkiAR prototype already allows any group member to request and subsequently take over the host role and start sharing their content with others. However, our next iteration of the system would certainly benefit from actual concurrent sharing support. Nevertheless, we believe that probing the prototype in the lab and in the field helped participants envision various application scenarios and provided the opportunity to include personalized content in a discussion in front of a map. This enabled us to collect design requirements and answer our research questions about perceived usefulness and purpose, system usability, and important types of content to share in a group when making the decision where to go next. On the plus side, however, the host-follower setup we employed might also be seen as supporting additional interactions beyond the originally envisioned decision-making use case. For example, skiers or snowboarders who just joined the group could use the content acquired by other "hosts" in order to "catch up" on the groups' prior activities. Similarly, remotely located people who do not participate in the skiing activity at all (e.g., friends or family at home), may still enjoy receiving updates and could thus "follow" and stay connected to the group. In these "out-of-slope" cases "follower" may benefit from the use of a tablet computer as exercised in the lab study instead of wearing a HMD.

While our lab and field participants found the system to be useful and stated that they would be willing to share information with group members in this fashion, actual user behavior can of course only be explored in an uncontrolled ("in the wild") natural setting. We observed a very different level of personal attachment to the content during our lab experiment (which used pre-defined content) in contrast to the field experiment that used actual personal content. Nevertheless, our goal was not to compare the two settings but rather to inform the design of content sharing systems in the context of outdoor winter sports using a variety of approaches. Two interesting aspects that our studies unveiled were the need to take *points-of-interaction* (i.e., the location where actual group decisions are taken) as well as the *temporal aspects of interactions* (i.e., the fact that those interactions are often time-constrained) into account when designing in situ content sharing systems that support decision-making encounters. These aspects already emerged with the help of our relatively simple video see-through based prototype. Future sport-tailored optical see-through head-mounted displays with accurate outdoor positioning might benefit from these two key design considerations by expanding spatial and temporal contexts for decision-making on the slope. It could be achieved by rendering augmented content on the real environment without occluding much of reality. For example, snow enthusiasts can explore benefits of in situ decision making and information sharing that the prototype affords while riding a long lift up to the mountain [7]. They are usually not pressed in terms of time, yet share physical space (and focal points) that prototype leverages.

Additionally, we have chosen traditional poster-size maps as shared *physical* reference points instead of a *virtual* one. On the one hand, a virtual map would allow skiers in a group to access customized content anywhere on the slope. On the other hand, presenting a shared virtual map on-slope might raise a safety issue. While we see the value of a virtual map in some cases, e.g. when one is lost and looking to catch up with a group, we believe that an AR map is more suited to stimulate collaboration between skiers. However, we hope that we will soon be able to take advantage of sport-specific optical see-through displays and thus directly examine the differences between physical and virtual shared references among skiers in a group.

Given the nature of the methodology we have chosen in our study – a qualitative inquiry – we had no control condition to measure the effect of our system for the activities that require collaboration, decision, and sense-making in front of a ski resort map. The lack of control condition is for two reasons: firstly, current navigation options (e.g. physical paper maps or digital maps on smartphone) do not take into account user-generated content; secondly, alternative setups (e.g. handheld AR [26]) are often found inconvenient for the winter context [8]. However, even though there is no direct equivalent to our system among traditional decision-making practices on the slope, future research would nevertheless benefit from a quantitative inquiry. Our current study provided a first set of insights into how technology might be used in collaborative skiing: what kind of personalized content can be used in decision-making within a group and how virtual augmentations of these content can be presented on the map with a shared physical focal point.

Last but not least, an interesting discussion arose around the issue of access control of shared personal content. Skiers and snowboarders should be able to decide how to share their information: publicly, within a group, or only with certain individuals. This points to a need for designing interfaces that can administer fine-grained access and usage control over shared data [21].

CONCLUSION AND FUTURE WORK

In this work, we presented the SkiAR system, a wearable augmented reality system for in situ sharing of personalized information on ski resort maps. We conducted a laboratory experiment with seven experienced pairs of skiers and an outdoor field study with twelve skiers and snowboarders. Our participants found SkiAR to be useful in tasks that aid decision-making, group organization, self-reflection, and that it helped to provide better awareness while on the slope.

We found that the interactivity that AR goggles and a wrist-worn controller offer, was considered useful and usable for sharing tasks among skiers within a group and beyond. We found that sharing and discussing hazards is crucial to make group decision where to go next (especially relevant when going off-piste in unfamiliar locations). Pictures taken during the day were considered less important for decision-making, but rather useful for a review after a ski day within a group. We described our design considerations for the systems, which facilitate in situ decision-making through content sharing and collected application scenarios for extending our system beyond outdoor winter activities.

In future work, we see value in building the next iteration of the system using optical see-through display dedicated for winter sports (e.g. RideOn ski goggles) and "winter-friendly" push-button controllers (e.g. Recon Instruments Snow2 MOD live remote). In order to better meet user needs we plan to augment personalized content beyond ski maps onto the real world and introduce implicit input capabilities inferred from the current context (e.g. detecting a ski queue from waiting at a ski lift). In addition, we plan to conduct controlled experiments and measure the usefulness of our system in collaboration tasks between group members with respect to traditional techniques used for in situ decision making (e.g. using paper maps with no personalized AR content, or using digital ski resort maps on smartphones). Finally, we believe that the general concept of SkiAR can also be extended towards non-sports situations, such as disaster simulation scenarios and other simulation practices using physical maps that involve group coordination and decision-making.

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