Advanced Interaction and VR/AR

Augmenting Humans on the Slope

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Two electronic devices that enhance safety and decision making.

In contrast to many other outdoor sports, skiing and snowboarding always entail the use of a significant amount of gear. This makes mountain slopes an ideal test bed for trialing novel augmentation technologies. Consumer electronics, such as smart watches, smartphones, and head-up displays, present a great opportunity for augmenting one's perception and communication capabilities on the slopes, e.g., for improving piste safety and the overall experience of decision making and coordination when practicing winter sports.

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In this article, we report findings from the deployment of two prototypes built from off-the-shelf components: the s-Helmet and SkiAR. The s-Helmet attempts to augment a skier's or snowboarder's movement perception of other enthusiasts on the slope via light detection and ranging (LIDAR) sensors mounted on the back of a ski helmet and warning light-emitting diodes (LEDs) on the front. The SkiAR facilitates the coordination and communication of groups on the slopes via the augmentation of panoramic ski resort maps with additional personalized information. Results from trials with the two prototypes, in both on-slope and off-slope settings, show that the technologies we developed and

With wearable cameras (e.g., mounted on the helmet), skiers can record their experiences and track their paths using positioning devices.

tested have significant potential to improve safety when practicing winter sports and to facilitate in situ decision making among groups of outdoor enthusiasts.

SAFETY AND SOCIAL NEEDS

Technology has always had an impact on how people practice and experience sports. However, today's consumer electronics have begun to take such impact to a whole new level, extending both the temporal and spatial boundaries of what we experience through sports. A plethora of wearable and portable devices, such as smartphones, smart watches, and heart rate monitors, provides continuous measurement of biophysical responses for analyzing and ultimately improving overall performance. At the same time, real-time workout sharing apps (e.g., Runtastic) allow one to share activities within his or her social network and even receive live feedback.

While much of this tracking and sharing focuses on just three outdoor sports—running, cycling, and hiking—other physical activities, in particular skiing and snowboarding, have much more potential when it comes to augmenting the pastime's experience. At the outset, winter sports such as skiing and snowboarding offer many additional options to accommodate wearable technology, simply due to the significant amount of gear involved (i.e., jackets, gloves, skis or snowboards, and helmets). Also, skiing and snowboarding are both highly social activities, often experienced in the company of others, which offers several interesting challenges for coordinating among both smaller and larger groups. Finally, because of the often harsh environmental conditions under which they are performed (e.g., icy slopes, avalanche risks, and hidden crevices or boulders), mountain sports present an increased risk of injury.

These hazards consequently dictate a profound need for safety, whereas the social aspect expresses the need for information sharing and coordination among peers who are not necessarily colocated. Safety is a top priority in all ski specializations (including piste skiing, backcountry skiing, ski touring, and so forth) and is usually addressed in the form of general protective equipment, such as helmets, back protection, thick garments, and tailored equipment for off-piste experiences, including avalanche beacons and avalance airbag system backpacks. Information sharing and coordination have thus far been accomplished by the use of mobile devices and specifically instant-messaging apps, VoIP apps, navigation apps, or simply phone calls.

Yet despite ubiquitous connectivity in the mountains [1], no information and communications technology advances have so far significantly disrupted the way safety and coordination needs are achieved on-slope. In this article, we describe two prototypes we have been developing in our laboratory—the s-Helmet and SkiAR—that attempt to augment a skier's perception and better support decision making and planning on the slope. While both systems are in their early stages, initial trials have opened promising avenues for research and development of innovative sports-tailored consumer technologies.

POPULAR TECHNOLOGY ON THE SLOPES

Mobile and wearable technologies and gadgets are already in use, and their presence on ski slopes is constantly increasing [1]. Back in the late 1980s, ski resorts started to use radio-frequency identification tags as an unobtrusive technology (attached to jackets or worn in pockets) to provide automatic and hands-free access to ski lifts. Later, the installation and extended coverage of mobile cell networks and data connectivity allowed users to explore short messages and mobile telephony for coordination. The proliferation of computing devices and sensor technology opened the way for researchers to design alternative interfaces for skiers and snowboarders, such as the Yo-Yo interface that navigates a simple one-dimensional menu through a mobile display attached to the wearable computer with a retractable string [2]. Moreover, the Hummingbird project explored the use of wearable computers, or so-called interpersonal awareness devices, to support communication between colocated group members, provide continuous awareness of the presence or absence of the members, and increase informal social interaction [3].

Today, the ubiquity of mobile devices, positioning technology, and video-capturing equipment allows skiers and snowboarders to continuously augment their experience on the slope. With wearable cameras (e.g., mounted on the helmet), skiers can record their experiences and track their paths using positioning devices. With continuous data connectivity, such recordings are usually shared online on social media platforms. Furthermore, today's dedicated winter sports apps [14] already enable outdoor enthusiasts to inquire about current slope conditions, locate and communicate with friends on the mountain, and log comprehensive field-performance data. However, such devices are far from ideal when it comes to on-slope use because of cumbersome gear such as gloves.

To address this issue, a number of start-ups and crowdfunding campaigns have recently announced products or prototypes that aim to solve the interaction problem and further enhance the skiing experience through personal devices placed in jacket pockets. The Forcite Alpine helmet [15], until recently a crowdfunding campaign, attempts to provide a one-size-fits-all on-slope solution by augmenting a typical ski helmet with a range of technological features, e.g., a high-definition camera and Global Positioning System (GPS) tracking. One interesting feature is the medium-range (200-m) radio communication support for small groups of up to three people, which enables peers to communicate in real time without the need to pause their activity.

The Recon Snow2 [16] is a commercially available head-mounted display similar in design to that in Google Glass, though specifically developed for alpine/winter sports. The Recon Snow2 offers a variety of features to help skiers track their performance, including the current speed, altitude difference, and distance covered. It also supports real-time friend tracking via onboard ski resort maps and an accompanying mobile app. The interaction with the head-mounted display is performed via a glove-compatible controller on top of a ski jacket's wrist, featuring a remote controller that has six stand-out buttons that can be easily pressed through a ski glove.

The RideOn [17] also started as a crowdfunding campaign and claims to be the first-ever augmented reality (AR) ski goggles that project real-time information onto a set of virtual layers at a distance of 5 m in front of the wearer. RideOn is based on the Android operating system, provides connectivity with mobile devices, and is expected to arrive on the market shortly.

s-HELMET: A SMART SKI HELMET FOR INCREASING ON-SLOPE SAFETY

Ski helmets have become a necessity for almost everyone on the slope, with some ski resorts establishing mandatory ski helmet use for children below the age of 16. Despite the constantly increasing adoption of helmets, part of which owes to more ergonomic and appealing designs, skiers who still refrain from using one often report interference with hearing as a reason for doing so. In fact, a study by Ruedl et al. found that wearing a helmet significantly reduces one's ability to accurately localize a sound source [4]. This means that a helmet wearer is less aware of his or her surroundings and potentially other skiers approaching from the back. If we also take into account habits such as listening to music via earplugs while skiing, this effect is further exacerbated and could potentially lead to an increase in on-slope accidents.

PROTOTYPE

We created the s-Helmet following a participatory and iterative design process for extracting the basic requirements, incorporating feedback from actual skiers and snowboarders. Based on the elicited specifications, we produced the design shown in Figure 1. The s-Helmet prototype comprises three LIDAR sensors, a microcontroller development board (Teensy 3.0), three LEDs, and two light lithium-ion polymer batteries (2,000 mAh each), all mounted on a regular ski helmet (size 60–62 cm).

The LIDAR sensors measure the distance of approaching skiers by detecting and analyzing the reflected laser beams emitted from the back of the helmet. LIDARs are extensively used in the automotive domain, primarily for collision avoidance and detection of large objects (e.g., other vehicles and pedestrians) [5]. While the LIDARs are able to detect approaching skiers up to 30 m away, we purposely limited their detection range to 5 m, as this distance seemed to strike a reasonable balance between offering sufficient warning and not being too sensitive. A quick back-of-the-envelope calculation shows that at a relative speed of 10–20 km/h (2.5–5.5 m/s) between two skiers offers about 1–2 s of warning.

The microcontroller board processes the LIDAR data inputs and notifies the wearer of the direction of skiers approaching from the back using three corresponding LEDs (left, center, and right). The LEDs are placed on the front of the helmet within the wearer's peripheral field of view to indicate from which side a skier might be approaching.

AIM AND APPROACH

The s-Helmet [6], [18] (see Figure 1) aims to augment a skier's peripheral perception of nearby skiers and their movement on the slope. It specifically focuses on traverse slopes—narrow slopes, often with minimal incline, that connect different ski areas or ski resorts. While the slight incline seems to imply less danger than on an actual slope, the lack of a grade, coupled with the long distance covered on such a slope, often means that skiers must enter such traverse slopes at high speed to cross them fully without the need for skating or, in the case of snowboarders, walking. These high speeds, combined with the often-narrow character of traverse slopes, make them significantly more dangerous than they seem.

Note that relative speeds between skiers during these encounters need not be high. At high velocities, simple movements by a skier in front can quickly cut off the path of an approaching skier, who may not have the time or the skill to avoid a run-in or a fall. This relatively constrained setting offers the opportunity to significantly increase a skier's awareness without the cost of greater cognitive load. Similar to a vehicle's side mirrors on a highway, a set of simple peripheral

FIGURE 1. (a) A participant wearing an s-Helmet prototype during the off-slope experiment. The (b) front view and (c) rear view of the s-Helmet.

A set of simple peripheral LEDs mounted on the helmet's frame can easily allow a skier to be aware of other skiers approaching from behind.

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OFF-SLOPE EXPERIMENT

To evaluate the effectiveness of our prototype, we conducted two experiments, with a total of 26 participants and skiing/snowboarding enthusiasts. The first study was intended to validate the concept of our prototype by approximating the traverse-slope conditions in an outdoor (but not on-slope) setting, where the subjects would simply walk a straight route wearing the s-Helmet while a researcher would approach from behind at different speeds. This was mainly for receiving feedback about our prototype over the summer and improving it further for on-slope experiments in the upcoming winter season.

For this first experiment we had 20 participants, with an average age of ~ 30 ($M = 29.9$, standard deviation [SD] = 6.488), ranging from 23 to 50 years old, whom we subjected to three conditions: normal helmet (condition A), s-Helmet (condition B), and s-Helmet while listening to music (condition C). In condition A, the subjects wore a normal helmet and walked a straight line while a researcher crossed behind them in a random zigzag fashion. The participants tried to identify from which side the researcher was approaching by lifting their corresponding hand: the left hand for the left side, right hand for right side, and both hands for the center. A supervisor registered the subjects' successful attempts to identify the position of the moving researcher. We permitted the participants to use any contextual cues to identify the position of the researcher behind them, such as shadows and noises, but we did not allow them to turn around and look. For condition B, everyone followed the same process, only this time the participants wore the s-Helmet, which offered the three LEDs to identify the position of the moving researcher behind them. Finally, condition C involved the use of the s-Helmet while the subjects listened to music via earplugs to simulate hearing interference.

After the end of each condition, we asked the participants to complete a NASA Task Load Index (TLX) questionnaire [7] for assessing self-reported mental and physical effort in percentages, while we registered their successful detection scores (a maximum of ten for the ten random movements we performed) for that condition. When the subjects completed all three conditions, they filled out a System Usability Scale (SUS) questionnaire [8] for assessing the overall perceived usability of the s-Helmet on a scale from one to 100. Finally, the participants completed a questionnaire inquiring about their skiing/snowboarding habits, and we briefly interviewed them about their thoughts and feelings regarding the prototype and the experiment.

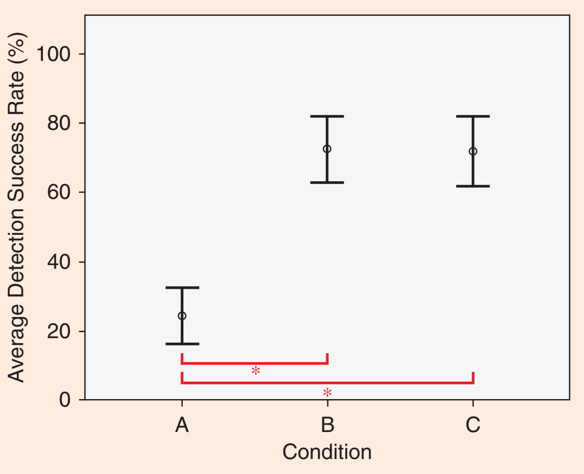

FIGURE 2. Our participants' detection scores per condition for the off-piste study. Condition A is with a typical ski helmet, condition B is with the s-Helmet, and condition C is with the s-Helmet while listening to music.

OFF-SLOPE RESULTS

While wearing the s-Helmet, participants were able to accurately detect the position of the researcher moving randomly behind them 70% of the time, as opposed to 20% when wearing a typical helmet (see Figure 2). With the s-Helmet while listening to music, our subjects detected the moving researcher just as accurately (70%) as in condition B. The average workload scores were almost equal across all of the conditions, with 33.95% (SD = 15.85) for condition A (normal helmet), 32.7% (SD = 14.65) for condition B (s-Helmet), and 34.81% (SD = 15.26) for condition C (s-Helmet while listening to music). Interestingly, when no augmentation was used (condition A), participants reported that they increasingly used contextual cues, such as shadows, for determining the position of the moving researcher.

Overall, the subjects evaluated the s-Helmet on average usability, with an average SUS score of 67.12 (SD = 13.08). (A system that achieves an SUS score of >68 is considered to be above average usability [9].) Novice skiers found the s-Helmet significantly more usable than did expert skiers. Moreover, people who would usually not wear a helmet on the slopes reported a significantly higher workload than people who ordinarily wear one. During the exit interviews, participants also reported a range of important usability issues, mainly regarding the feedback mechanism employed in our prototype. The most commonly reported issue was the LEDs' placement either too close to the wearer's eyes or, at times, outside the wearer's field of view. Despite the issues reported, our subjects were positive about the s-Helmet's usefulness and thought the device could potentially increase overall on-slope safety.

ON-SLOPE EXPERIMENT

For assessing the effectiveness of the s-Helmet on the slopes, we conducted a limited trial on actual traverse slopes in a ski resort with six male participants (four skiers and two snowboarders), with an average age of ~30 ($M = 29.833$, $SD = 2.124$) (see Figure 3). We first properly insulated all of the critical electronic components (i.e., main board) to avoid contact with the snow. Since we were trying the s-Helmet for the first time on actual slopes, we wanted to obtain a baseline score for future on-slope trials with the next versions of our prototype. As a result, to avoid inducing fatigue in our participants that might influence our baseline formation, we narrowed down our study design to two simple conditions: s-Helmet active and s-Helmet inactive, while following the same procedure as before, with a researcher skiing behind a subject and an observer keeping a record of how many times the participant successfully detected the position of the randomly approaching researcher.

FIGURE 3. Some of our subjects testing the s-Helmet on actual ski slopes.

When a condition was completed, participants filled out a NASA TLX questionnaire. Once both conditions were completed, we administered an SUS survey, as well as a questionnaire inquiring into the subjects' skiing/snowboarding habits. We also briefly interviewed participants about their thoughts and feelings regarding the prototype and the experiment.

ON-SLOPE RESULTS

Our on-slope results showed that with the s-Helmet active, participants were able to accurately localize the approaching researcher 40% of the time, as opposed to 5% when the device was deactivated. Notably, our participants' reported expertise levels on the slope did not differ significantly from the those of our subjects for the off-slope study. Similarly, we found no important differences between the average TLX and SUS scores from the on-slope trials ($M_{TLX} = 35.52\%$, $SD_{TLX} = 18.04$ and $M_{SUS} = 67.08$, $SD_{SUS} = 17.42$, respectively) and the TLX and SUS scores obtained off the slope ($M_{TLX} = 32.7\%$, $SD_{TLX} = 14.65$ and $M_{SUS} = 67.12$, $SD_{SUS} = 13.08$, respectively). The on-slope and off-slope TLX scores, in particular, displayed almost the same workload as wearing a typical ski helmet (~34%). Participants' comments on the slope were somewhat similar to those for the off-slope study, with some subjects communicating they could not see the middle LED and one reporting he could not use his goggles during the trials.

DISCUSSION

The goal of the s-Helmet is to gradually warn users of skiers approaching from behind. Clearly, the usefulness of such an approach critically depends not only on the technology used to assess approaching skiers, but also on the notification system used. Our on-slope results already showed that LEDs may not be ideal in many circumstances. Better integration into the helmet as well as increasing their intensity might alleviate some of these issues. Additionally, light sensors could adaptively control the brightness of the notification LEDs to accommodate a wider range of lighting conditions (e.g., sunny versus cloudy, open sky versus forest). Using audible feedback might be even more robust, yet care must be taken to ensure such a system is not too noisy. Whether audible or visible, the notification system must gradually warn of incoming skiers, lest a warning startle users and cause them to suddenly change course, which could actually incur—instead of prevent—a run-in with a skier from behind.

Second, the robustness of detection would need to be carefully tuned so that one avoids too many false alarms. A combination of the two notification systems—audible and visible—might offer an interesting option to improve reliability. The LEDs could be geared toward low false negatives but potentially show a few false positives, while audible notifications would only indicate incoming skiers with high probability (i.e., a low rate of false positives).

SkiAR: A WEARABLE AR SYSTEM FOR PERSONALIZED CONTENT ON SKI RESORT MAPS

In our second prototype, we approached the question of slope safety through real-time information- and experience sharing. Skiing and snowboarding are undoubtedly highly social activities. One important type of social activity in skiing is decision making in a group: which piste to take next, how to catch up with friends for lunch or après-ski, and also what areas to avoid when going off-piste [10].

Conventionally, skiers and snowboarders consult ski resort paper maps or large-scale maps mounted along the slopes, We developed SkiAR, a wearable AR system that supports groups of skiers and snowboarders with their on-slope decision-making processes.

which offer a basic navigational overview of the ski area. However, such panoramic maps do not support the sharing of any personal content (e.g., recorded GPS tracks) or customized context (e.g., relevant points of interest and hazards) that are often the basis for making such decisions. While today's social media platforms, instant-messaging services, and dedicated ski-resort apps on skiers' smartphones in principle support such activities, these are far from ideal, given the often harsh environmental conditions on a ski slope. Based on design requirements that we extracted from prior work, we developed SkiAR, a wearable AR system that supports groups of skiers and snowboarders with their on-slope decision-making processes [11], [19].

PROTOTYPE

Ski goggles, a helmet, and gloves are typical skiwear features. We built our prototype with a vision of using ski goggles as an output display to provide additional information to skiers and snowboarders. Our prototype design is in line with good AR practices and principles, defining first the use case (i.e., skiers sharing content on a ski map) along with the corresponding user requirements and then selecting the adequate AR presentation device (i.e., a head-mounted display) [12]. Therefore, our prototype consists of an AR application running on a smartphone—worn using a head-mounted holder—and a wrist-worn input device to control the presentation and sharing (see Figure 4). We decided to use a wrist-worn controller in our setup to eliminate the trouble of having to take out a phone. Our SkiAR prototype approximates future technologies (as head-mounted see-through displays for active sports and hands-free input interfaces) with the help of a smart watch for control and a conventional smartphone that is mounted in a head-worn phone holder.

The sharing of personal and contextual information among members of a winter sports group is not only crucial for safety but is also often one of the key ingredients of a positive skiing experience [10]. Our prior empirical study with a group of backcountry skiers showed that the most important information they shared within a group was reference information necessary for descent, the up-to-date location of skiers in a group, and captured photos and videos. Consequently, our first prototype supports sharing four types of GPS-enriched content: pictures, tracks, points of interest, and hazards. The prototype uses a custom-designed algorithm that allows it to easily map location-tagged personal content (e.g., GPS tracks) onto the corresponding coordinates of a traditional artistic map of a ski resort.

LABORATORY AND FIELD STUDIES

The aim of our prototype is to aid decision making and in situ information sharing among skiers or snowboarders in a group. To inform the design and validate the usability and perceived usefulness of our prototype, we conducted two initial user studies:

1) an in-depth evaluation of the system with seven groups of skiers in the laboratory
2) a field experiment to evaluate the prototype outdoors in a ski resort in the Alps with 12 participants.

We first performed the controlled laboratory experiment, recruiting seven pairs of skiers with various levels of experience. The age of our 14 participants (three of whom were female) ranged from 22 to 34, the average being 28 ($SD = 4.1$). We recruited the subjects in pairs to approximate actual in situ group decision making on the slopes. We asked them to envision various conventional decision-making scenarios in front of a poster-size ski map (i.e., returning from a lunch break, meeting a group member at the end of the day, and planning the following day). The task of one was to describe the ski day through reviewing and sharing predefined virtual content (pictures, points of interest, tracks, and hazards) on the map to plan the next day together with another.

FIGURE 4. A participant browses through digital content overlaid on a panoramic resort map.

For the field experiment, we recruited 12 skiers and snowboarders with various levels of experience during a weeklong winter retreat at a ski resort in the Alps. The ages of our 12 participants (two of whom were female) ranged from 25 to 36, the average being 28.9 ($SD = 3.25$). Every day throughout a week, one researcher invited one or two of the subjects to ski together during a morning or an afternoon and, subsequently, to meet for a study session in front of a board-sized

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map at the resort. During the ski run, the participants and the researcher took pictures together, recorded tracks, and added a few hazards that they encountered on the way. The actual study session in front of the map took, on average, 15–30 min.

First, we briefed the one or two subjects (on two occasions we had a pair) on the goal of the study, requested their consent, and then asked them to try the prototype, which showed localized sample content previously entered into the system by the researchers. In contrast to the laboratory study, here we did not have any predefined scenarios, but rather simply asked participants to decide where to go next, given the current state of the content added to the system earlier (see Figure 4).

In both investigations, we asked our subjects to complete a poststudy questionnaire, in which they needed to indicate their level of agreement on several statements regarding the usefulness of the SkiAR system, using a five-point Likert scale (see Figure 5). Additionally, we administered an SUS questionnaire [8] to evaluate the usability of the system and a NASA TLX workload test [7] to evaluate the mental, physical, and temporal demands of the system. Finally, after both studies, we conducted a semistructured interview. We recorded all interviews using a voice recorder, then transcribed the recordings verbatim.

To analyze these data, we followed an iterative process, going back and forth between them, the researchers' notes, and the emerging structure of the empirical categories, which was developed through repeated readings of the material. To draw out the common factors in the system, we adopted a contextual design methodology and constructed an affinity wall [13]. The goal of this part was to unveil the user experience with the prototype, define ideas for new content and applications of the SkiAR system, and collect suggestions for the design of technologies that could be used to support skiers and snowboarders in group decision making on the slopes. The qualitative evaluation helped us to better understand this rich space descriptively and to shed some light on the design challenges and opportunities of interactive systems for collaborative skiing.

RESULTS

The participants in both studies regarded the SkiAR system as generally useful to have during skiing or snowboarding. Figure 5(a) shows that subjects in the field study generally gave higher scores (higher perceived usefulness for the system in general, as well as for each functionality—review, share, and add). In contrast, participants in the laboratory 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. We speculate that this may be because field study participants were in a more realistic setting, facing an actual decision-making activity.

Next, we were interested in evaluating the usability of the head-mounted display setup, an approximation of the envisioned high-technology skiwear. The system achieved an average SUS score of 73.75 (SD = 12.46) in the laboratory and 79.19 (SD = 10.07) in the field study, which suggests that the apparatus we developed is above average in usability [9].

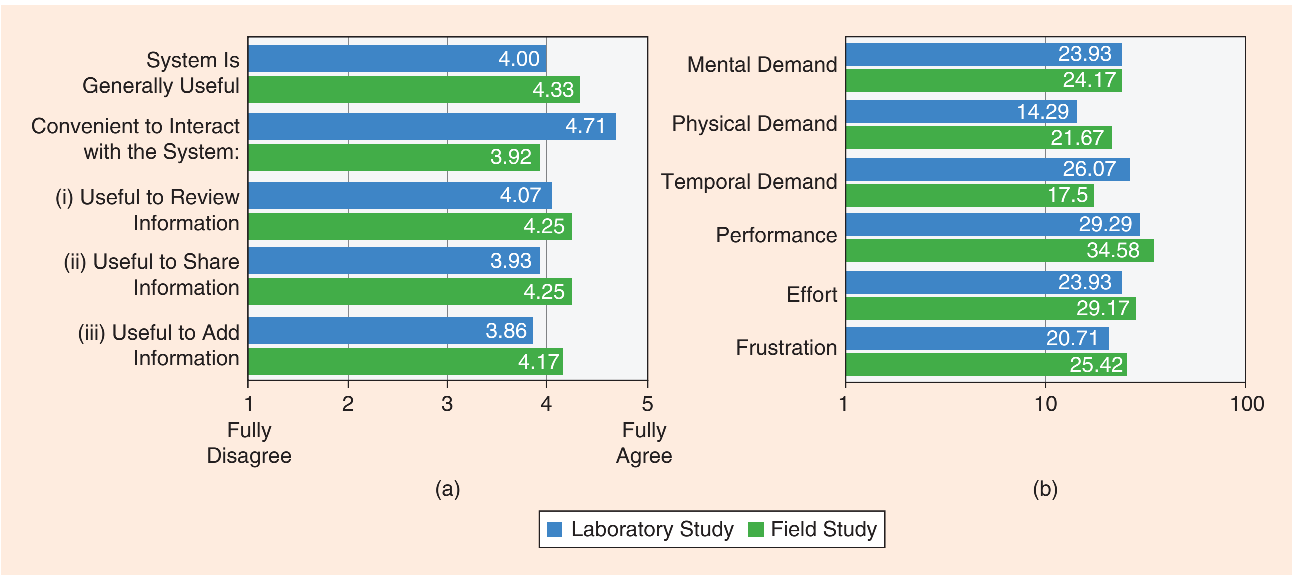

FIGURE 5. (a) The perceived usefulness of the SkiAR system. (b) The NASA TLX average score on the content reviewing task, represented on a logarithmic scale (a lower value is better). Laboratory study: $N = 14$. Field study: $N = 12$.

Finally, we evaluated the content review task using the NASA TLX questionnaire. Figure 5(b) presents the respective mean values of the mental, physical, and temporal demand. It also shows self-assessment for performance, effort, and frustration. The total average workload reported scored 23.04% ($SD = 9.91$) in the laboratory study and 25.42% ($SD = 12.32$) in the field experiment, respectively. The lowest parameters measured were physical demand (laboratory) and temporal demand (field), and the highest was self-performance.

We speculate that the high score in performance derived from the markerless technique for visual tracking that we employed. Especially for the outdoor scenario, the tracking system showed a rather weak performance on sunny, clear days, when many reflections occurred on the map. Participants needed to find an initial point with respect to a map where tracking worked best before starting to review the content. We hypothesize that other tracking techniques (e.g., point cloud tracking or edge tracking) might result in better performance.

During a semistructured discussion portion at the end of each session, participants provided valuable insights about scenarios where the SkiAR system could be used, and suggested extensions to the system for better meeting skiers' and snowboarders' needs. Four categories emerged during our qualitative analysis:

1) the perceived purpose of the system
2) augmented content
3) suggestions for interaction design
4) envisioned application scenarios of the system beyond winter activities.

Our subjects found SkiAR to be useful in tasks that aid decision making, group organization, and self-reflection, and felt that it helped to provide better awareness while on the slope. We provide a summary of the findings that emerged from a thematic analysis of the participants' contextual interviews and observations. The report of our in-depth details and discussion are available in a separate publication [18].

We found that sharing and discussing hazards is crucial in making group decisions about where to go next (which is especially relevant when going off-piste in an unfamiliar location). Group members considered pictures taken during the day to be less important for decision making, but instead useful for a review after a ski day within the group and beyond it, for storytelling purposes. Additionally, the subjects mentioned that future augmented human technology for the slopes should afford the current location and the status of skiers within a group as important content. Beyond that, they felt that, when it comes to decision making in situ, it would be advantageous for the prototype to include waiting times at a ski lift, up-to-date contextual data (e.g., weather, visibility, and snow conditions), and reference information (e.g., deals on the daily menu at a restaurant, discounts on rental equipment, and the last bus schedule).

Next, two interesting aspects that our studies showed were the need to take into account 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) when designing in situ content-sharing systems that support decision making. For example, we observed that interaction with a shared ski map is rather short, with people quickly deciding where they want to go. On the other hand, during a lift ride, people often have more time to discuss their decisions. An explicit follow-up mechanism could be useful, allowing one to pick up a prior conversation and/or decision taken (e.g., during a lift ride) and present it again at a later time (e.g., at a poster-sized map).

Finally, we found that the general SkiAR concept can also be extended to nonsports situations, such as disaster simulation scenarios and other simulation practices, using physical maps that involve group coordination and decision making.

DISCUSSION

Given the nature of the methodology we chose for our study (a qualitative inquiry), we had no control condition to measure the effect of our system for the activities that require collaboration, decision making, and sense making in front of a ski resort map. A control condition was lacking for two reasons.

1) Current navigation options (e.g., physical paper maps or digital maps on a smartphone) do not take into account user-generated content.
2) Alternative setups (e.g., handheld AR) are often found inconvenient for the winter context.

However, even though there is no direct equivalent to our system among traditional decision-making practices on the slope, future research would benefit from a quantitative inquiry. Nevertheless, we believe that probing the prototype both in the laboratory and 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 decisions on where to go next on a ski slope (or even off-piste). 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 this content can be presented on a ski map.

We further argue that the SkiAR prototype enabled decision making on the slope and group coordination that are crucial not only for the overall safety of the group but that also contribute to overall skiing enjoyment. In particular, specialized disciplines, such as backcountry skiing and ski touring, require comprehensive awareness of environmental conditions and hazards that could be present in the off-piste skiing areas. Thus, informing all group members about potential dangers that have been spotted or making the right path selection can be vital for the safety of the skiers as a group.

FUTURE WORK

Despite the preliminary positive results, our studies face some significant limitations. For example, the s-Helmet is far from being a one-size-fits-all solution for detecting skiers/snowboarders approaching from the back on any slope. Our system approximates a rear-view-mirror analogy for traverse slopes, addressing a limited but significant source of on-slope accidents. Extending this approach to other slopes seems infeasible. Typical ski trajectories are much too complex and variable for a simple range-finder-based system to not only capture, but also to properly interpret. In fact, even a perfect radar-like overview might fail because of the much higher speed differentials often involved on standard slopes.

Both prototypes have seen limited on-slope testing. Our next iterations will have to take our early findings into account, incorporate them in their respective designs, and then undergo testing again on the slope with larger numbers of participants, also including older age groups. As for the SkiAR prototype in particular, a new iteration should include the full slope experience, not only in front of a stationary resort map but in every aspect where decision making typically takes place (e.g., at ski lifts). One interesting research avenue for the s-Helmet prototype could be Nordic skiing, where skiers typically move along straight and narrow slopes, occasionally gaining considerable speed on inclines. For the SkiAR prototype, a useful addition would be to include on-demand virtual maps and present virtual reference points on real terrain during ski runs whenever decisions are needed to be made.

CONCLUSION

Our two prototypes, the s-Helmet and SkiAR, offer an interesting glimpse into today's opportunities for next-generation on-slope consumer electronics, in particular with a view toward safety and coordination. The s-Helmet uses a rather simple concept—head-mounted range finders—to improve safety in the constrained yet relevant setting of traverse ski slopes. SkiAR offers a more generalizable approach that still requires further exploration and testing to understand its full potential. Overall, we believe that our early prototypes have opened promising avenues for research and development of creative sports-oriented consumer technologies.

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