Augmenting Skiers' Peripheral Perception

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ABSTRACT
The growing popularity of winter sports, as well as the trend towards high speed carving skis, have increased the risk of accidents on today's ski slopes. While many skiers now wear ski helmets, their bulk might in turn lower skiers' ability to sense their surroundings, potentially leading to dangerous situations. In this paper, we describe our "Smart" Ski Helmet (S-SH) prototype. S-SH uses a set of laser range finders mounted on the back to detect skiers approaching from behind and warns the wearer about potential collisions using three LEDs mounted at the helmet's front edge, slightly above the wearer's eye level. In this work, we describe a controlled experiment with 20 ski and snowboarding enthusiasts and a follow-up on-slope deployment with 6 additional participants of varying levels of expertise. Our findings indicate that the S-SH can significantly increase skiers' peripheral perception on traverse trails.

Author Keywords
Ski safety; Peripheral perception; Peripheral vision; LIDAR; Distance tracking.

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

INTRODUCTION
As alpine skiing has become a popular winter pastime, ski safety is an increasingly important issue. Although head injuries comprise only 3 - 15 % of all injuries skiers suffer, their numbers are rising [18]. Maybe not surprisingly, ski helmets have become a necessity for almost everyone on the slope today. Unfortunately, a considerable number of skiers still abstain from using a helmet. The most commonly reported reasons are the belief that ski helmets increase risk taking behavior, and/or that they impair one's vision and hearing. While studies have shown that ski helmet use is neither associated with risky behavior nor with impaired vision [17], there is evidence that helmets do impair hearing, e.g., when trying to locate a sound source [16]. Built-in headphones for listening to music exasperate this effect.

Figure 1. Left: A user wearing S-SH. Top right: Front view of S-SH with 3 LEDs feedback system. Bottom right: Back view of S-SH with 3 LIDAR sensors, a control unit and 2 batteries.

In this work, we present an evaluation of our Smart Ski-Helmet (S-SH) [13] (see Figure 1), which notifies its wearer about other skiers moving in from behind. Its simple notification mechanism attempts to prevent close on-slope encounters that could result in accidents. While general piste conditions are often complex, the problem is somewhat simplified on a particular style of piste: the traverse. A *traverse piste* is an intermediate trail connecting different pistes within the same ski area. A traverse piste is usually flatter and narrower than a typical ski slope, greatly limiting approach trajectories of skiers coming from behind. At the same time, the narrow setting of a traverse piste, together with the high speeds of skiers and snowboarders (who need to compensate for the lack of incline with high velocities), quickly leads to dangerous congestions even with only a few skiers underway. Consequently, being aware of skiers moving behind is highly important on a traverse slope. Ultimately, we envision S-SH providing the same utility as a car's side view mirror (wing mirror) when on the highway.

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RELATED WORK

Prior work on peripheral displays utilizes the human peripheral sight as an extra channel of information [4, 7]. For example, Costanza et al. proposed the use of peripheral, "near-eye" displays for delivering mobile notifications that are noticeable, unobtrusive both to the users and to the users' surroundings, while supporting a customizable degree of disruption [5]. More recently, Luyten et al. developed a usable visual language that can be employed for supporting basic interactions via head worn peripheral displays. The authors found that the use of simple high definition shapes from a limited set of available shapes, as well as the incorporation of motion and the use of the three basic colors (i.e., red, green, blue), increased the overall successful recognition of shapes that were projected in one's peripheral view [12]. Several technological augmentations have found their way into winter sports, even if only experimentally. For example, the "motion echo snowboard" augments a typical snowboard with a display mounted on the upper part of the board [15]. The display then provides real-time feedback of the snowboarder's weight distribution while snowboarding. The setup is purposed for increasing awareness of one's posture on a snowboard and helping one to learn snowboarding faster. Similarly, a real-time "sonification" system was developed by Hasegawa et al. for helping one maintain one's perception of center of gravity while skiing and particularly encourage novice skiers to lean forward (counterintuitive but nevertheless correct skiing posture) [10]. The system employs earplugs for delivering any feedback about one's posture. The "SkiAR" prototype utilizes a HMD and augmented reality for sharing personalized content on ski resort maps [7]. The authors showcase how their approach can increase overall coordination and communication on the slopes. The authors illustrate how different prototypes can synergistically augment humans on the slope [14]. Higuchi et al. introduce the use of a drone that captures real time video of athletes performing sports from a 3rd person perspective, while the video is streamed to a head mounted display (HMD) worn by the athletes for improving their cognition and motivation through mental imagery [11]. Additional feedback modalities have been proposed in literature for augmenting one's perception. The "Haptic Radar" prototype aims at increasing one's spatial awareness with a so-called "artificially extended skin" [3]. In essence, the prototype is a headband equipped with a series of infrared proximity sensors providing the user with 360 degrees of spatial awareness via haptic feedback coming from mounted motor vibrators. Blindfolded stationary participants wearing the "Haptic Radar" could successfully avoid objects moved towards them by moving their heads in an evasive fashion. Similarly, the "ProximityHat" prototype aims at increasing one's perception of their surroundings [1]. The authors presented results from a study with 13 blindfolded participants navigating indoors using the "ProximityHat", while receiving feedback from pressure actuators positioned around the head. The participants could successfully navigate in hallways and even find doors. "SpiderVision" is a similar concept that uses a HMD and two cameras, one mounted on its front and at its back for presenting a blended image of front and back perspective at the same time [6]. The concept of augmenting one's spatial perception has also been explored for the workplace. For example, Cobus et al. designed a HMD prototype for delivering multimodal notifications in emergency assistance settings intended for first responders [4]. Utilizing the waist wearable space, Ferscha et al. introduced a belt-based "vibro-tactile" notification system that enables one to sense one's surroundings via one's waist [8]. The authors claim their prototype could be useful in the workplace, where one could be traversing a physical space covered with obstacles, while receiving feedback in the form of "vibra-notifications".

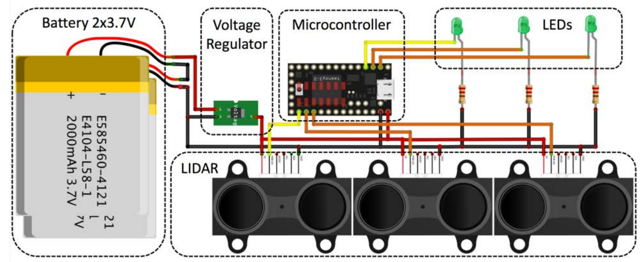

Figure 2 – Connection diagram of the S-SH prototype (diagram created with Fritzing)

With S-SH we strived for designing a wearable that will be lightweight and robust enough to support the dynamic movement of a skier/snowboarder, in contrast to the less dynamic settings in prior work (e.g., the "ProximityHat" [1]). Also, since skiing and snowboarding entails a significant amount of vibrations, we decided to use visual feedback instead of tactile feedback. Next, we describe our prototype system and we report on findings from both on-slope and off-slope trials.

SYSTEM OVERVIEW

The prototype system (Figures 1 and 2) consists of three light detection and ranging (LIDAR-Light v1) sensors, a microcontroller development board (Teensy 3.0), three standard 5 mm green LEDs, two 2000 mAh Lithium-ion Polymer batteries, a 5V voltage regulator (L7805), and a ski helmet (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. The sensors use time-of-flight technique, i.e., they calculate the delay between the transmission of the laser beam and the reception of the reflected returning signal. Each sensor uses a single Class 1 laser beam that can detect distances up to 40 meters with accuracy of ± 2.5 cm. The laser beams are repeated at 50 Hz frequency emitting optical signal of 905 nm wavelength, total power of 1.3 W, and beam diameter of 12x2 mm. The sensors consume 105 mA in the idle state and 130 mA when emitting the beam (at 4.75 - 5.0V). Each sensor is 20x48x40 mm in size with a weight of ~ 22 grams. The LIDARs are fixated on the helmet using Velcro straps pointing in three directions: left, center, and right. Orienting the sensors in different directions eliminates interference problems. The Velcro allows easy adjustment of the sensor positions, e.g., for participants' heights.

The Teensy 3.0 board processes data input from the LIDAR sensors and notifies the helmet wearer about skiers at the back via three LEDs (left, center, and right). The board has a 32-bit ARM Cortex-M4 CPU operating at 48 MHz, 128K Flash and 16K RAM memory, 14 analog inputs, and 10 digital outputs. The LIDAR sensors are connected to the board through three analog inputs. The board uses a simple, manually tuned threshold algorithm to visualize the presence of skiers within a certain distance. The LEDs produce continuous green light of 150 - 200 mcd when the distance of moving skiers is less than the threshold.

The LIDAR sensors can detect targets up to 40 m away. We limited the detection range (threshold) to be a maximum of 5 m. This distance seemed appropriate for the use on traverse slopes to detect approaching skiers and to filter out false positives caused by one's surroundings (e.g., trees, rocks). The prototype system is powered by two 2000 mAh batteries. The two batteries provide enough power, regulated by the 5V voltage regulator (L7805), for the microcontroller, LIDAR sensors, and LEDs. Also, using two batteries allowed us to mount the off center while still maintaining the helmet's balance.

STUDY DESIGN

Our initial study aimed at evaluating the effectiveness of our prototype in successfully warning the wearer about people moving behind the wearer's back. In our follow-up trials, we tested S-SH prototype in real on-slope settings with a limited number of participants. In particular, we wanted to answer the following three research questions:

i. Can participants wearing the prototype perceive people moving behind them? If so, how accurate can they be?

ii. Can participants wearing the prototype perceive people moving behind them when also listening to music?

iii. Will participants find the system easy to use, and will they find it useful for increasing on-piste safety?

Methodology

As we developed S-SH over the summer, we first tested it by approximating traverse-slope conditions in an outdoor setting that has the study participant walk along a straight route while a member of the research team crosses from behind at various speeds (running, cycling, walking). For answering the research questions above, we formed 3 conditions within this setting:

A. **S-SH OFF.** Participants wear S-SH without the LEDs enabled, and signal any presence they can detect behind their backs by lifting their corresponding arm left, right, or both for center (control condition).

B. **S-SH ON**. Participants wear the S-SH prototype with the LEDs enabled, and signal any presence they can detect behind their backs by lifting their corresponding arm left, right, or both arms for center.

C. **S-SH ON & music.** Participants wear the S-SH and a pair of earplugs and listen to (self-selected) music. Participants signal any detected presence by lifting their corresponding arm left, right, or both for center.

All participants underwent all three conditions in counter-balanced order (i.e., a within-subjects design).

Participants

We recruited our participants (26) from our University through mailing lists, newsletters and by contacting student sports services. We purposefully aimed for students since these are often more active and generally more involved in sports. We selected our participants based on their interest in skiing/snowboarding, but did not limit recruitment to a minimum level of expertise, since we were also interested in evaluating the system's usefulness for both amateurs and experts. None of the participants had serious visual impairments, and all but one had no hearing problems.

Measures

Profile. For each participant, we collected demographic information and general information about one's skiing/snowboarding annual activity as well as, one's expertise level and the age one started exercising winter sports. We also asked about their helmet wearing habits and whether they regularly listen to music while on piste.

Detection score. For each condition, we recorded a detection score variable. The experimenter moved randomly behind the participants' backs performing 10 movements. Participants were instructed to report those movements as they happen. Each time a participant correctly reported an experimenters' movement/position, a point was added to a detection score variable, which ranged from 0 to 10 (i.e., all movements were correctly reported).

TLX. For each condition and upon ending, we asked participants to complete a raw NASA TLX questionnaire (i.e., without pairwise comparisons). TLX is a widely used multidimensional tool for subjective self-reporting of mental and physical load when performing a task [9].

SUS. At the end of the study, we asked participants to complete a SUS-scale about the S-SH prototype. SUS is a simple ten-item questionnaire that provides a general view of subjective assessments of usability of a system or interface [2]. SUS scores range from 0 up to 100. Typically, everything that achieves a usability score of above 68 is considered above average.

Qualitative. After the SUS, we engaged each participant in an open-ended discussion with the aim of revealing additional insights in the form of observations or ideas.

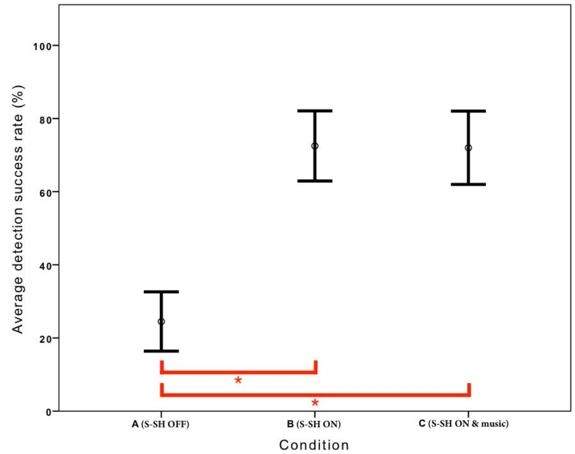

Figure 3. Percentage of successful attempts to locate the person moving behind per condition type: A. typical ski helmet (S-SH OFF), B. S-SH ON and C. S-SH ON and listening to music.

Procedure

For the off-slope study, trials took place on a large square in our University campus. We first briefed participants about the study, its purpose and its duration. Then, we collected the participants' informed consent and asked them to answer the initial demographic and skiing/snowboarding profiling questions. Next, we presented to them the S-SH prototype and described the study procedure.

In each condition, participants were asked to wear the S-SH and walk normally in a straight line for ~ 30 m. During the walk, the experimenter approached participants from behind at a distance of 2 - 5 m in random combinations of left, right and center directions. The participants were specifically instructed to keep looking forward (i.e., not directly at the LEDs) and indicate any perceived presence behind them by lifting their corresponding arm (e.g., for someone moving at the back left they would raise their left arm). After each condition, participants were asked to complete a NASA TLX questionnaire on a laptop (using the official NASA TLX desktop app [19]). After all conditions were completed, participants were asked to complete an online SUS questionnaire about the S-SH prototype. We finally recorded any comments and thoughts from each participant. All participants underwent all three conditions. We specifically counterbalanced only condition B (S-SH ON) and C (S-SH ON & music) for eliminating any carry over and learning effects, since condition A (S-SH OFF) involved the use of S-SH as a typical helmet and was intended only for obtaining a baseline for comparison with conditions B and C.

RESULTS

In the first study (off-slope), we recruited 20 participants, with an average age of ~ 30 years old (M = 29.9, SD = 6.488) from the University's premises. Participants were all winter sports enthusiasts, of which 13 were skiers (65 %) and 7 were snowboarders (35 %) of varying expertise levels and were all affiliated with the University, either as students or as employees. Participants rated in overall their skiing or snowboarding expertise as above average (M = 3.4, SD = 1.273) in a scale from 1 (novice) to 5 (expert) with an average prior experience of 19 years (M = 19.6, SD = 9.928). The majority of the participants (45 %) stated that they ski for less than 5 days per year, followed by 5 to 10 days (25 %), 15 to 20 days (15 %), 10 to 15 days (10 %) and more than 20 days per year (5 %). Most of the participants indicated that they ski/snowboard in groups of 2 to 4 people (70 %), followed by groups of 5 to 6 (20 %), whereas 10 % reported that they ski/snowboard alone. Most of the participants always wear a helmet (60 %), whereas 15 % reported that they never use it. Participants mentioned that the reason they refrain from using a helmet is price and the feeling of being free:

"[P5] *I never bought it (helmet) because I had a hat and it is cheaper.* [P6] *No I don't use a helmet. I 've never used it and I 'd like my head to feel free because I ski like 6h in a row…*"

Moreover, 75 % of the participants reported that they never listen to music while skiing/snowboarding because they want to stay focused, alert about their surroundings and enjoy the nature:

"[P9] *I don't usually listen to music when I snowboard because maybe am too much focused on my movements, on my legs and also because I am scared I can't sense someone coming from behind.* [P6] *Because I like to be in the nature, see the landscape and music distracts me and of course I would like to concentrate on skiing*".

S-SH Effectiveness

For answering our first research question, whether participants were able to detect people moving behind them when using the S-SH prototype, we investigate the effect of condition type on detection scores (see Figure 3 for the percentage of successful detections by condition). A Shapiro-Wilk test did not confirm the assumption of normality for the independent variable condition type (A: p = .017, B: p = .049, C: p = .044). Thus, a non-parametric Friedman test displayed a significant difference in the detection scores achieved for each condition ($\chi^2(2)$ = 27.079, p < .001). Post hoc Wilcoxon signed-rank tests using the Bonferroni correction revealed a significant difference in the detection scores (p < .001). Median detection scores for A (S-SH OFF), B (S-SH ON) and C (S-SH ON & music) conditions were 2 (2 to 3), 7 (6 to 9) and 7 (6 to 9), respectively, in a scale from 0 to 10. There were significant differences in detection scores between condition A and B (Z = - 3.836, p < .001) as well as, between A and C (Z = - 3.814, p < .001), but no significant difference between conditions B and C (Z = 0, p = 1). This answers our initial research question (**i**), with participants being able to locate the person moving behind them 70 % of the times, when using the S-SH prototype, as opposed to 20 % with a typical ski helmet. In most cases, participants reported that when using the S-SH they were not only able to detect the person's position behind them, but also the person's direction of movement:

"[P4] *Well sometimes, in the second part of the test, I could determine that one light was turning on after the other and I thought it was a movement pattern.* [P14] *Sometimes all three (lights) turned on sequentially, that means the person was crossing the line (from one side to another).* [P16] *But I saw them (lights) blinking in a sequence and I could infer a vector of direction but not always, the middle one was a bit unreliable.* [P19] *When the person crossed yes, because you could clearly see the LEDs turning on from right to left and left to right.*"

In fact, in some cases participants reported that they would even anticipate or predict the direction of movement of the person behind them:

"[P5] *I could see that there was a continuity between the movements, I saw there was a person on the right then on the center then on the left, so I expected he will come back again on the center and he did.* [P9] *So, when I saw the right light and then the central one then I was expecting to see the left, so I was kind of predicting your movement. Because if you snowboard and you move from the right to the center you are supposed to be on the left next. So, I was predicting your movements, that was useful.*"

Surprisingly, participants using the S-SH while listening to music (S-SH ON & music) were equally accurate to just using the S-SH (S-SH ON), achieving an equal success rate of 70 % (see Figure 3). This not only answers our initial research question (**ii**) in whether participants using the S-SH while listening to music would be more accurate in detecting people behind them than they would be when wearing a typical ski helmet, but also surpasses our initial expectations. In fact, this indicates that listening to music had no effect on participants' ability to localize people moving behind them while using the S-SH prototype off the slopes.

For assessing the cognitive and mental effort that participants underwent in each of the three conditions, we performed an analysis of variance with the overall TLX score as a dependent variable and the condition type as an independent variable. Shapiro-Wilk tests confirm the assumption of normality for the independent variable condition type (A: p = .226, B: p = .449. C: p = .785). However, the analysis of variance revealed no significant main effect for the condition type ($F(2,57) = 22.534$, p = .911, $\eta_p^2 = .003$). In fact, the overall scores TLX scores in a scale from 0 to 100 were almost equal for all conditions (A: M = 33.957, SD = 15.851, B: M = 32.707, SD = 14.652, C: M = 34.818, SD = 15.267). This indicates that in general participants put roughly the same physical and mental effort in detecting a person moving behind them when wearing a typical ski helmet, the S-SH ON and the S-SH ON while listening to music. Though, a more in depth analysis for each of the items of the TLX questionnaire reveals some interesting trends. In particular, a multivariate analysis of variance with the score of each of the six items that comprise the overall TLX score as dependent variables and the condition type as independent variable, showed a significant main effect of condition type on participants' perceived performance score ($F(2,57) = 11.437$, $p < .001$, $\eta_p^2 = .286$). Indeed, post hoc tests using the Bonferroni correction showed that participants in condition B (S-SH ON: M = 49.9, SD = 23.692) and C (S-SH ON & music: M = 47.5, SD = 22.651) rated their performance significantly greater than in condition A (S-SH OFF: M = 20, SD = 19.325), in a scale from 0 to 100. This indicates that when participants were actively using the S-SH, even while listening to music, they were significantly more confident that they had accurately located the person moving behind them than they were with a typical ski helmet. In fact, during condition A (S-SH OFF), participants reported increased use of contextual cues such as shadows:

"[P2 similarly P13] *In the first condition I couldn't hear anything, I perceived the person behind me by the shadow*."

When all conditions were completed, participants were asked to complete an SUS questionnaire, assessing the overall usability of S-SH. The overall SUS score achieved was 67 (M = 67.125, SD = 13.085), indicating that in principle S-SH was rated of average usability. Generally, participants agreed (on a scale from 1 to 5) that S-SH is a system that someone would learn to use quickly (M = 4.2, SD = 1.005), was easy to use (M = 3.45, SD = 1.099), and they would use it frequently (M = 3.3, SD = 1.031). Similarly, participants disagreed that S-SH is a system that someone needs to learn a lot of things in order to use (M = 1.55, SD = .944), someone would need tech support in order to use (M = 1.75, SD = 1.208) and that it is unnecessarily complex (M = 2.25, SD = .966). In principle, these scores answer our research question (**iii**) in that participants found our prototype easy to use. However, short open-ended discussion sessions at the end of the experiment revealed some important flaws in our design.

In overall, participants reported a range of important usability issues, mainly regarding the S-SH feedback mechanism. Often, those issues caused participants to get distracted from the primary task of following the line and focused on the LEDs instead. The most common issue was the LED placement: either they were too close to each other, and/or too close to the wearer's eyes:

"[P6 similarly P8, P9, P12] *The main problem is that there are 3 lights/LEDs, I can't really understand which is the right and which is the middle. I can really distinguish between the left and the right but not the middle. I can see like 5 LEDs or something. This is the main problem.* [P8] *I got confused with the lights the middle one and the left one, it was an issue.* [P12 similarly, P19] *It is really near the eyes and it is very difficult to see if it is the right or left.* [P17] *The thing that was obvious to me is that when you*

Figure 4. On-slope field trials. A participant wearing the S-SH and a researcher skiing behind him.

had the middle light on it was really hard to say whether it is a light at the edges or one in the middle."

The next most important reported usability issue was the placement of the 3 LEDs being too high in front of the wearer's eyes that caused the participants to constantly look up to receive feedback, occasionally distracting them from the primary task of looking at the line. This issue was often considered as potentially dangerous for on-piste usage:

"[P2] *Maybe the lights should be a bit more down or to the side because I couldn't see them, I had to look up and by looking up, if I were skiing, I could easily fall*. [P3] *In the beginning* (condition A*) I was stressed because I had to look at the line and I ended up looking up for the lights*. [P4] *It was kind of annoying that they were on the top and I couldn't really see them. It wasn't that difficult but If I were skiing it would be a problem.* [P16] *For the helmet maybe the feedback system is (positioned) a little bit too high*. [P17] *When you are skiing you are usually looking down so it would be a bit hard to look up in this situation*." LED brightness levels and color were also found insufficient or inadequate, especially in times of increased sunlight: "[P5 similarly P6, P11, P20] *It was good but it was very difficult to see the indications.* [P21] *…I didn't see them* (LEDs) *that well and I don't know if green is the right color to use for the lights*. [P8] *If you are in the sun maybe you can't see the lights anymore*."

Despite the important usability issues, most of the participants agreed that S-SH is a useful approach that would increase safety in the piste (**iii**):

"[P14 similarly P15, P19] *The idea is very good because in many cases you have accidents on the slopes because of the fact that you don't see someone behind you coming very fast, it is a great thing for safety*."

Some participants proposed color encoded LEDs for distinguishing between different directions ([P3 similarly P16]), others suggested different feedback modalities, such as audible and tactile ([P20 similarly P7]) cues, whereas others proposed a combination of stimuli for reinforcing feedback ([P9]). Some proposed embedding the visual feedback mechanism into typical ski goggles ([P3 similarly P5, P14, P16]) or even using augmented reality (AR) for projecting an overlay of information on a ski mask ([P3 similarly P5, P17]). Finally, one participant proposed a mobile app that connects to the helmet and produces an audible cue when someone approaches while using earplugs for listening to music ([P3]).

On-Slope Field Trials

To verify the ecological validity of our study, we tested the S-SH prototype in a limited field trial with 6 participants (2 snowboarders, all males) with an average age of ~ 30 years old (M = 29.833, SD = 2.124) on an actual traverse slope in a ski resort (see Figure 4). The slope was of average difficulty with the maximum slope gradient of 25 % (i.e., "blue"[1]) and traffic was mild. The width of the slope was around 5 meters the length of the traverse was approximately 900 meters. The slope was machine groomed at the beginning of the day and the weather conditions varied from low overcast to snowy that created a soft packed terrain at the end of the day. We recruited participants in their natural settings (i.e., after they already have made several runs downhill) to make our field trial as close to the real skiing experience as possible (e.g., in terms of fatigue) and aim to have both beginners and experienced skiers.

Similarly to the off-slope trial, an experimenter performed 10 random movements behind participants backs approaching them from various directions from the back with an average speed of 20 to 30 Km/h. Participants indicated the perceived direction of approach by lifting their left hand for back left, right hand for back right and both hands for center. A nearby researcher registered correct localization attempts. Similarly to the off-slope trials, we stressed our participants not to directly stare at the LEDs, but look straight ahead and utilize their peripheral vision instead for perceiving when a LED blinks. Due to none of our participants having the habit to listen to music while skiing, we narrowed down our on-slope study design to 2 conditions (i.e., S-SH ON and S-SH OFF). We measured detection scores for both conditions, whereas TLX and SUS scores were only obtained for the S-SH ON condition. Non-parametric Mann-Whitney U tests showed that our participants' median expertise on the slope (Mdn = 4) did not differ significantly from that of participants off the slope (Mdn = 3.5) (U = 58.5, p = .929), although participants on the slope were skiing for significantly less years (Mdn = 11.5) than participants off the slope were (Mdn = 20) (U = 27, p < .05). Nevertheless, a Wilcoxon signed-rank test showed that the S-SH on the slopes (Mdn = 4 | i.e., 40 %) still significantly improved skiers' ability to detect skiers from behind when compared with no detection

[1] Austrian classification ÖNORM S 4610, 4611

system (*Mdn* = .5 | i.e., 5 %). Independent samples *t*-tests revealed no significant differences between both TLX and SUS scores obtained on the slope (TLX: M = 35.526, SD = 18.044 | SUS: M = 67.083, SD = 17.422) and scores obtained off the slope (TLX: M = 32.707, SD = 14.652 | SUS: M = 67.125, SD = 13.085) (TLX: $t(24) = -.393$, p = .698 | SUS: $t(24) = .006$, p = .995). One participant noted that he could not see the middle light ([P25]) and one other complained he could not use his mask during the experiment and thus could not see the lights ([P26]).

DISCUSSION

Typical ski helmets are notorious for hindering one's ability to accurately locate a sound source [16], potentially leading to dangerous situations. In fact, we were able to confirm this phenomenon with participants achieving to accurately locate a person moving behind them only 20 % of the times. In contrast, when wearing the S-SH, participants' detection rates rose to 70 %. Surprisingly, this effect persisted even when we temporarily impaired participants' hearing with music, displaying the same average detection rate (70 %). This indicates that S-SH may hold a significant potential to augment one's peripheral perception in the piste, since one's hearing capacity is generally distorted due to the helmet. In fact, the majority of the participants reported that they never listen to music while skiing/snowboarding (75 %) in their effort to stay focused on skiing and alert about their surroundings. Interestingly, we were able to prove the value of S-SH in the wild via a limited on-slope deployment with 6 participants. Participants' detection rates with S-SH activated reached the level of 40 % as opposed to 5 % when without detection support. The majority of the participants reported that apart from the person's position behind them, they were also able to infer the person's direction of movement. In many cases they mention that they could even predict it by the sequential fashion of light activation of our visual feedback modality. This complements the efficiency of our approach and the ecological validity of our study.

However, participants also reported a series of important usability flaws mainly concerning the feedback mechanism. For most, the LEDs were positioned to closely together and to the eyes hence, making it often difficult to detect which one is activated. In addition, we believe that having only one prototype and one large-sized helmet (60 - 62 cm) did not work best for all participants. As a result, the helmet often tilted back and up with some participants commenting that the lights are located far up and outside of their field of view hence were difficult to see. Also, other participants reported that the lights were too dim or the color (i.e., green) was inappropriate. All these issues combined, affected participants' ability to use the helmet and influenced their perceived usability measures. In fact, S-SH achieved a general SUS score of 67 for both off and on slope tests, which is considered of average usability. Interestingly, workload scores did not differ significantly among conditions, indicating that S-SH (off-slope: ~ 33 %, on-slope: ~ 35.5 %) entailed the same workload as a typical ski helmet (off-slope: ~ 34 %). However, perceived detection performance was significantly higher for S-SH as opposed to a typical ski helmet, indicating participants' increased confidence when using our prototype. In general, participants' engagement was high, along with the perceived value of our approach and many proposed ideas and design alternatives for improving it further.

Limitations

Apart from a range of usability issues unveiled during the study, the core limitation of our approach is its functional range detection, deliberately restricted to only 5 m, down from a theoretical limit of 40 m that the LIDAR sensors support. This was imposed by the fundamental simplicity of our approach, which employs plain distance measuring. Thus, for avoiding generating false positives caused by one's nearby surroundings such as trees and practically anything at the height of the wearer or higher (a very steep slope too), we had to artificially limit the detection range. In fact, false positives generated from an increased detection range could misinform the wearer to abruptly change course in unforeseen ways and potentially lead to collisions. However, we think that 5 m detection range is still sufficient for warning the wearer about a following skier/snowboarder, especially on a narrow, crowded traverse slope, and essentially discourage the wearer from skiing carelessly at those moments (e.g., spontaneously changing skiing side).

Clearly, a 5 m distance will not be a sufficient detection range for perceiving and avoiding a fast approaching skier. We have tested S-SH in a naturalistic setting on machine groomed and soft-packed traverse slopes with occasional moguls. To better understand the potential scalability of our system, we would need additional tests on diverse types of slopes (e.g., regular, wide slopes, demanding slopes with a higher gradient), as well as tests that have more than one person approaching (ideally at different speeds). Also, examining S-SH in different weather conditions may be helpful.

Our next iteration of the S-SH prototype will need to have the sensors better integrated into the overall helmet shape, without any loose parts that might fall off or cause additional injuries.

CONCLUSION

Our S-SH prototype has shown the potential of alerting skiers to other skiers approaching from behind. In our outdoor off-slope experiment, we found that S-SH provided a 50 % improvement in one's peripheral perception while wearing a ski helmet. This improvement was at the level of 35 % when on an actual traverse slope. Interestingly, SUS and TLX were almost equal between off- and on-slope settings. Also, listening to music, which would in many cases be considered a distraction, had no effect on our participants' ability to detect a person behind them when using our prototype off-slope.

By further investigating the best notification modality (LEDs, audible, tactile, or a combination thereof), S-SH may ultimately be able to increase overall piste safety, or even enable people with disabilities (e.g., impaired hearing) to exercise winter sports more safely and confidently. Also, the general concept may be applicable to other types of sports as well (e.g., cycling).

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