Improving the Visual Perception and Spatial Awareness of Downhill Winter Athletes with Augmented Reality

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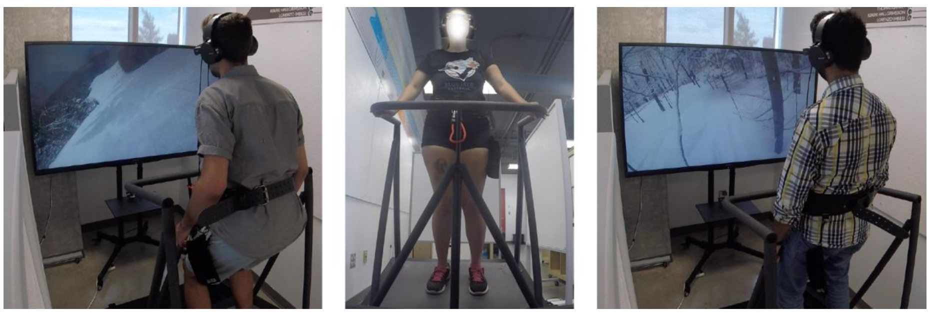

Fig. 1. Participants Standing on the Platform During Experience Simulation Testing

Abstract. This research study addresses the design and development of an augmented reality headset display for downhill winter athletes, which may improve visual perception and spatial awareness, and reduce injury. We have used a variety of methods to collect the participant data, including surveys, experience-simulation-testing, user-response-analysis, and statistical analysis. The results revealed that various levels of downhill winter athletes may benefit differently from access to athletic data during physical activity, and indicated that some expert level athletes can train to strengthen their spatial-awareness abilities. The results also generated visual design recommendations, including icon colours, locations within the field-of-view, and alert methods, which could be utilized to optimize the usability of a headset display.

Keywords: Augmented Reality · Interface · Winter Sports · Spatial Awareness · Visual Perception

1 Introduction

Spatial awareness is essential to the performance and success of any athlete but is especially important to winter sports athletes participating in high-speed sports, where a split-second decision could be the difference between success and failure, which could result in injury [16]. Having faster reaction times to terrain changes and visual stimuli may give them a competitive advantage in competition and similarly having good peripheral awareness may also improve their chances of success both at training runs or competition. Downhill winter athletes have, "underlined the importance of visual perception for optimal performance, even though they seem to rather unconsciously perceived visual information during races" [21].

Wearable solutions can offer a technological advantage in sports and games. Particularly, users can benefit from Augmented Reality (AR) headsets for live monitoring of useful information such as biometric and spatial data without losing the sight of "the real world" [5]. For example, an AR headset is used for pocket billiards that gives related visual information to the player and increases the activity's success rate by calculating the distance to the target with dashed lines between six pockets and the balls for an effective shot [24]. Physical status and biometrics information can also help as visual information to improve the visual and spatial perception of an athlete during an activity in order to increase athletes' performance [14]. Yet there are no studies on how to effectively present such data on a Head-Mounted Display (HMD) screen for extremely fast-paced sports such as downhill skiing. In this paper, we investigate how downhill winter athletes can benefit from AR HMD by determining the usability and evaluating different visual design choices to deliver the data to the athletes. Our investigation is based on designing a prototype and running an empirical study of athletes with different skill levels. We propose recommendations and guidelines for AR displays, including icon colours and location within the field-of-view, and the alert methods that could be utilized to optimize the usability of a headset display.

2 Related Work

2.1 Use of Biometric Data for Athletes

In recent years, several wearable products have been released for tracking individual performance. Athletes who participate in sports like running and cycling are already utilizing wearable devices, such as wristbands and headset displays, to read biometric data during and after performing a physical activity [5]. Athletes can improve visual and spatial perception and receive constant feedback with monitoring physical conditioning with biometrics such as pedometers, accelerometers, and heart rate monitors. The most common type of wearable device for athletes is a set of systems classified as personal information systems that "help people collect and reflect on personal information" [15]. Personal information systems can facilitate opportunities to share information between coaches and athletes [23]. Biometric sensors embedded in wearables devices can provide coaches and athletes with performance data [3].

2.2 Mixed-reality Technologies in Exercise and Skiing

Schlappi et al. [21] suggest that HMDs and AR can improve the user's daily lifestyle, and will "help fill in the blind spots and take the guesswork out of everyday living by supplementing the myopic vantage of real-time experience with a continuous, informatics mode of perception." Delabrida et al. [8] created an AR application that can be used with mobile phones and printed 3D HMDs to measure the distance between objects. Recon-jet goggles are specifically designed for cyclists or long-distance runners. Recon Jet includes a dual-core processor, dedicated graphics, Wi-Fi, Bluetooth, GPS, webcam and a sensor designed to turn on the device when it is equipped [7]. Oakley Airwave snow googles deliver informatics on the HUD speed, such as air time, vertical feet, navigation, and a buddy tracking for snowboarders moving down the slope [1]. There has been other a qualitative analysis based on interviews with top-level downhill winter athletes [21], however there is no study yet that investigates their effectiveness and various usability aspects.

Head-mounted displays can have negative effects on the safety level of an athlete when the virtual action is not necessary for athlete's posture. One rule is "not disturbing the user's behavior with a virtual object and allowing freehand interaction" [10]. Icons and numerical data should be displayed in the periphery and not the center of the user's field-of-view, as it could cause major visual distractions and occlude environmental objects like signs, lights, trees, and rocks. While the main benefit of using HMD is that the user can see navigation information regardless of where they are looking, the display may block or at least cover a certain portion of the real-world view [12].

2.3 AR Display Design

When designing dynamic icons for visual screens, Gestalt principles related to the visual perception of 2-dimensional images can be adapted for AR headset displays. In a study on Gestalt theory in visual screen design, Chang et al. [6] list the key Gestalt principles. From the eleven Gestalt principles Chang listed, our icon most benefited from having a single focal point, and using visual perception of closure and simplification using uncluttered graphics. HUD used a single icon, to prevent complex graphics and ambiguous conclusions. Too many focal points are likely to confuse learners and diffuse their interest. Int he core of our graphics by using x and y graph, we allowed the individual perceive the form as a complete together and apply closure with the icon and the screen.

The location, colour, and opacity of elements, or icons within visual displays, especially head-mounted displays, can affect the visual perception of the person viewing the display. Schömig et al. [22] suggested a landmark-based map when using head-mounted displays. Landmarks can suggest any place, object, or feature that persists in the Heads-Up Display (HUD). Navigational scenarios, route-finding, or distance to turn would aid users to help with navigation.

Albery [2] developed and tested SORD, a complex HMD system used by military pilots. It was composed of a tactile vibrating vest, a helmet-mounted visual display, and 3D audio headphones. This multi-sensory HMD system allows pilots to bring their attention to external visual tasks outside the cockpit, without having to continuously return their attention to the aircraft attitude instruments on the dashboard. The SORD allows the pilot to monitor airspeed, altitude, heading, bank and pitch of the aircraft in real-time, reducing the pilot's workload by eliminating the requirement to frequently monitor the cockpit displays and controls [2]. It was found through extensive research that HMD symbology used by pilots, "should be designed to support an efficient instrument scan, support other mission-related symbology, and utilize as little of the display as possible" [9].

Ito et al. [11] compared the effects of icons and text using Heads Up Display, and the results indicated that presenting more letters increases the speed of information. On the other hand, spending long durations looking at the displayed information has a potential risk of accidents. Bartram et al. [4] conducted visual perception test studies, which indicate that blinking icons will capture the end-user's attention more effectively translational or rotational motion. Nozawa et al. [19] created an initial study as a VR experience for indoor ski training with a slope simulator. The results show that athletes overcome cybersickness by following a pre-recorded expert motion animation and learn by copying their body gestures.

As far as we know, there has not been a user study evaluating the visual design requirements of augmented headset displays for winter downhill athletes. Our goal is to investigate the visual design requirements for an augmented headset display for downhill winter athletes. Based on our research gaps, we identify the following research questions.

- Can downhill winter athletes benefit from access to spatial orientation data and other important athletic information during physical activity?
- How can sensory modalities and technologies be integrated to transmit unobtrusive data to the athletes?
- What visual format is the most effective to deliver the data to the athletes?

3 Research Design

3.1 Prototype Design and Development

Visual perception, dynamic visual acuity, and quick reaction times to visual stimuli are proven to be essential to the success of high-level athletes [17, 21, 20]. A wearable headset could likely deliver essential information most effectively to the athlete while not being overly obtrusive and distracting during physical activity. The increased awareness could potentially improve success rates and prevent injury.

Military aircraft pilots and extreme downhill winter athletes have many similarities, which may indicate that AR headsets and principals utilized by military pilots could also be utilized to benefit downhill winter athletes. Similar to downhill winter athletes, pilots as well have the capacity to use their visual senses to receive necessary data without being distracted [18]. Recent HUD and HMD design principles that are used by the military AR displays, and their icons could potentially be utilized to support efficient variable scanning for downhill winter athletes because pilots similar to athletes require spatial orientation data and other biometric information. A comparison with the results of military pilots [18] can contribute to new recommendations or guidelines for downhill winter athletes (See Fig. 2).

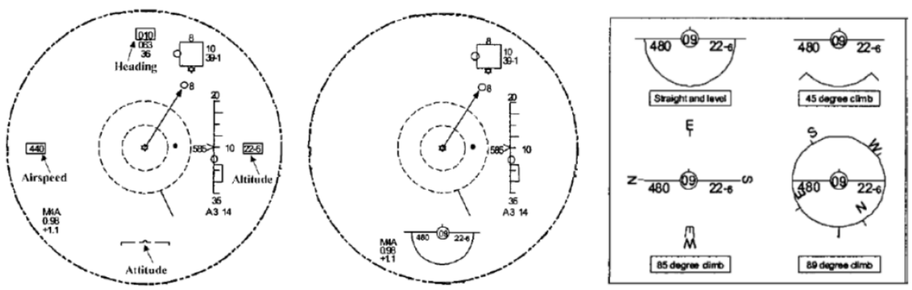

Fig. 2. Icons Used by Military Aircraft Pilots (left) During Flight [9]

To investigate the use of AR HMD, we developed a prototype (See Fig. 3) consisting of three different parts; an Augmented Reality Head Mount Display, a projection of a video that displays a first-person view snowboarding experience, and a physically elevating platform to simulate a downhill skiing experience.

During the experiment, the slope changing platform moved in sync with the changing angle of the hill in the downhill simulation video, played on the screen. The platform began each simulation at a position of 5 (a beginner level slope, green circle) and for the slope angle test changed to 14 (blue square) for the 2nd interval, 20 (black diamond) for the 3rd interval and back down to 9 (green circle) for the final 4th interval. The angle intervals were selected based on the information by Kipp [13] which revealed that in North America; green circle slope gradient: 6-25% (0-11), blue square slope gradient: 25-40% (12-18), black diamond slope gradient: 40% (19 and up).

The main structure of the slope changing platform was constructed using rectangular steel pipes welded together to support the weight of participants who weighed within the range of 100-250 lbs. The structure had to be sturdy to withstand the force of participants leaning side to side while the platform changed its slope. A remote control, electric car jack powered by a heavy-duty, 15-amp, DC motor with a lift capacity of 4000 lbs was sourced and used to power the changing angle of the platform.

A wireless headphone was worn by participants to create background sound effects such as mountain wind sounds on the loop, which also helped cancel the sound of the electric motor and platform moving.

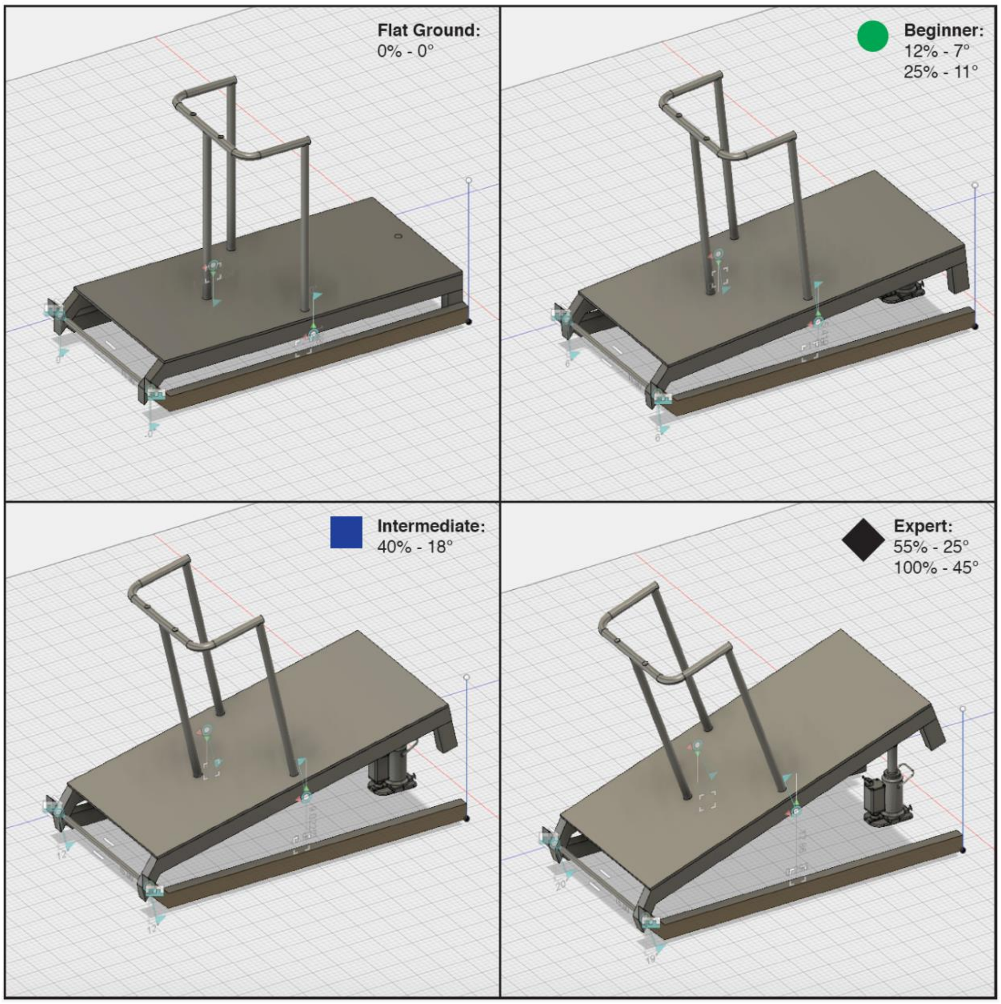

Fig. 3. Isometric Plans of the Testing Platform Design and Associated Equipment

During the experience, participants wore both wireless headphones and a Moverio BT-200TM smart glasses headset 10). Participants stood on a specially designed, slope changing platform, in front of a large, high-resolution television screen to test an icon developed, within a simulated downhill winter environment. The Moverio BT-200TM was powered by a smartphone controller, which was stored in a pocket on the safety harness during test simulations and linked by a charging cord, which was somewhat obtrusive. Icons and symbols currently have been used for AR displays by military aircraft were used as guidelines for developing the icon for this research 5). The icon was designed to be simple and easy to read, displaying only the athlete's downhill speed, vertical altitude on the mountain, and, most importantly, the current slope angle of the hill.

Fig. 4. The Moverio BT-200 Smart Glasses Worn by Participants (Google Images)

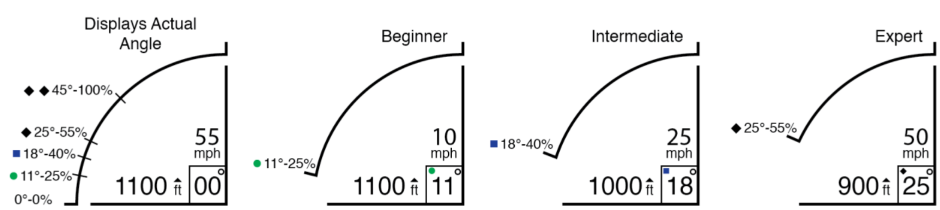

Fig. 5. Icon designed for Moverio Headset Display experience testing

3.2 Research Approach

Experiment Design The visual icon (See Fig. 5) displayed in the HMD was used to assess different variables of visual perception during four test scenarios:

1. Icon color scenario,
2. Icon location scenario,
3. Icon alert method,
4. Icon slope angle indication method.

During the first scenario, participants stood on the platform and viewed the icon displayed in the headset, which changed to a different colour every 7 seconds, based on the visual spectrum of colours or ROYGBIV (Red, Orange, Yellow, Green, Blue, Indigo, Violet). The hypothesis for this first scenario was that participants would rank the green icon as having the best clarity and visibility, because green iconography has been previously tested, used and proved the most effective by military pilots [18]. A secondary hypothesis was that the red icon would also be ranked high due to its stark contrast to the outdoor winter environment with colors of green, white and blue.

The other two scenarios to evaluate icon alert mode and icon location followed a similar structure, allowing participants to input their feedback immediately after viewing the different icons.

During the fourth scenario (icon slope angle indication method), the participants determined the angle of the slope changing platform, stood on during the simulation, by shouting out the estimated angle value at three specific time intervals during the 90-second simulation video.

During the first part of the fourth scenario, participants were instructed to make an educated guess and attempt to determine the exact slope angle value of the platform at that specific interval, using only their spatial awareness abilities and without any icon displayed in the headset for assistance.

During the second part of the fourth scenario, the participants watched the same 90-second simulation video, but this time the headset displayed an icon that indicated the angle value of the slope changing platform in real-time. Instead of using spatial awareness abilities and making an educated guess, the participants looked at the icon displayed in the headset to read and state aloud the slope angle value at the same time intervals.

The experiment was a within-subject design using predefined independent and dependent variables. The test results are the subjective quantitative data which are formed from the answer of the participants were questioned about the usability and visual perception of the displayed icon. To evaluate the data of the success and preference rate of the four scenarios above, we used visual perception criteria and operationalize them as our dependent variables for the different scenarios. The independent variables of this test were the different scenarios manipulating the color, location, method of alert the icon. (See Fig. 6, 7, 8) To assess the accuracy of spatial awareness of athletes, we ran the scenario one final time without using the headset and the visual information.

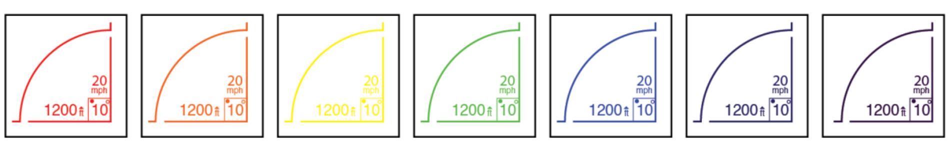

Fig. 6. Icon Colours (from left) Red, Orange, Yellow, Green, Blue, Indigo, Violet

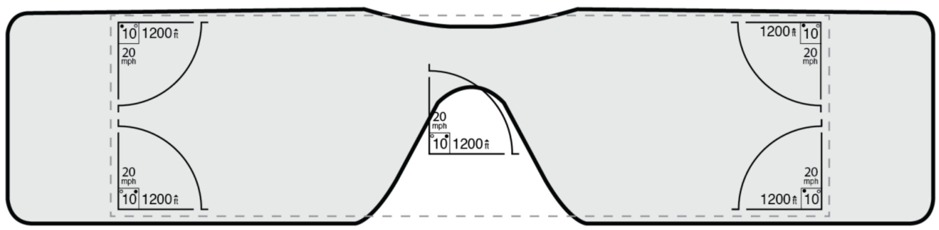

Fig. 7. Icon Locations in the Headset Display: Top-Left, Bottom-Left, Middle, Top-Right, Bottom-Right

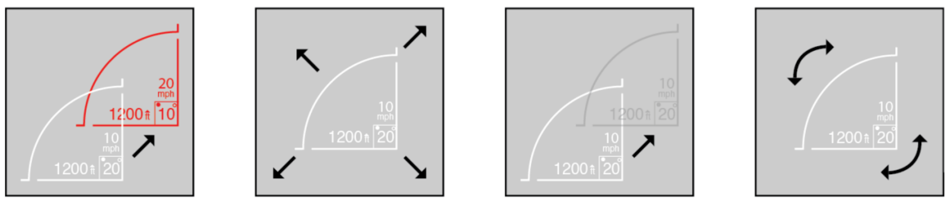

Fig. 8. Icon Alert Methods: Colour Changing, Expanding, Blinking, Rotating

Participants During the study, 34 participants with previous experience skiing, or snowboarding at different skill-levels were recruited. Participants were recruited through university and online winter sport athlete communities. Participants were initially screened for their expertise in snowboarding/skiing and using Head-Mounted Displays. The requirements were to be between 18 – 55 years of age with good vision and not having any injuries or disabilities. The user testing was conducted at the researchers' university in a private room with no external noise or visual distractions present.

Apparatus The key features of the prototype are as follows:

1. Moverio BT-200: an augmented reality headset used to display the icon during the testing.
2. Wireless Headphones: played ambient mountain wind sounds during the entire simulation,
3. Remote Controlled Electric Car Jack: used by the primary researcher to change the slope, angle of the platform during the simulations, had an angle range of 5 to 20,
4. High-Resolution Screen: used to play first-person, simulation videos recorded on real ski hills by the primary researcher, positioned close to participants to feel more immersive,
5. Safety Harness: a belt worn by participants, clipped to the safety railing to prevent falling,
6. Safety Enclosure: padded metal railing that participants held onto during the simulation,

7. Rubber Floor Pad: gave the participants extra foot grip when the platform angle was steep,
8. GoProTM Cameras: two cameras were used to record front and side views during testing.

Procedure The experience simulation testing sessions were conducted over a 31-day period, with 34 total participants, and were approximately 30 minutes in length from start to finish.

Each participant first read and filled out a consent form, followed by a pre-test survey and skill level assessment. After all the required surveys and documents were completed, the participants were instructed to step onto the slope changing platform and were fitted with the equipment to perform the experience simulation testing.

After each scenario was completed, the participants were given the post-test survey sheet to rank the different coloured icons from the best, most visible and easy to read icon displayed by the headset, to the worst and least visible icon (1=best, 7=worst). Participants finished the study with a 1-on-1 interview with the researcher, which allowed each participant to express any final comments.

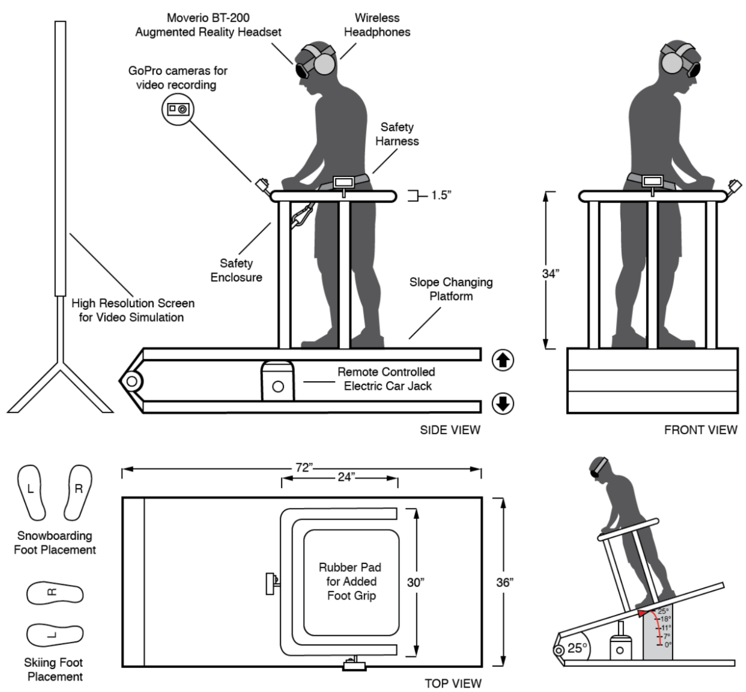

Fig. 9. An orthographic drawings of the setup for snowboarding simulation testing

Fig. 10. The Moverio BT-200 Smart Glasses Worn by Participants (Google Images)

4 Results

4.1 Data Collection

The participants were combined of 9 male skiers, 8 female skiers, 9 male snowboarders and 8 female snowboarders, for a final ratio of 52% male and 48% female for both skiers and snowboarders. A specific number of male and female, ski and snowboarding participants were selected to ensure that the sample size and results of participant testing sessions were reflective of the Canadian Ski Council ratios. Statistics gathered and presented by the Canadian Ski Council showed that in 2015 a total of 58.3 % of Canadian downhill skiers were male and 41.7% female, and of all Canadian snowboarders 61% were male and 39% female.

Pre-test survey indicating participants' skill level in ski or snowboarding resulted as 10 participants (29%)at the beginner level, 7 participants (21%) at the intermediate level, 16 participants (47%) at the expert level and 1 participant (3%) at the competitive level.

When participants were asked if they knew what "augmented reality" was 23 participants (68%) indicated yes and then wrote their own definition, while 11 participants (32%) indicated that they did not know what AR was. Next, when participants were asked if they have used AR devices during an activity, 29 participants (85%) indicated that they had never used an AR device before, 3 participants (9%) indicated that they had rarely use AR devices, 1 participant (3%) indicated that they sometimes use AR devices, and 1 participant (3%) indicated frequent use of AR devices.

The first part of the post-test survey determined the effect of each of the four variables (icon colour, location, alert method, and slope indicator). The post-test survey asked questions that related to the icon display features and system usability, which the participants responded to using a Likert-scale such as:

- The level of difficulty to determine the slope angle value with/without icon assistance,
- Determine if the interface helped you to determine the slope more quickly or accurately,
- Indicate if it would be useful to have access to this data while riding,
- What group of athletes would benefit from this display? (beginner, expert, etc.),

- What senses are best suited for transmitting this data to the athletes?
- How natural and comfortable viewing the headset felt during testing?
- How much you learned about augmented reality during the study?

In the second part of the post-test survey, participants were given a chance to write any additional comments that could help improve the overall experience and usability of the AR headset and icon. The user response analysis method helped identify issues with the display that multiple participants experienced, while also confirming some findings and results from other data collected, supporting the final conclusions.

4.2 Data Anaysis

Icon Colour The seven icon colours used during this research study were; red, orange, yellow, green, blue, indigo and violet (See Fig. 6). Participants gave each colour a rank, 1 for best to 7 for worst.The results indicated that the orange coloured icon was ranked with the best average rank or mean (mean = 2.91 1.44), followed closely by the red icon in second (mean = 2.94 1.82) and the green icon in third (mean = 2.97 1.51). The yellow icon was ranked fourth (mean = 3.5 2.08), blue in fifth (mean = 4.0 1.60), indigo in sixth (mean = 5.56 1.26) and violet (mean = 6.12 1.37) was ranked as the worst overall in seventh place.

Therefore, this data suggests that the orange, red and green coloured icons were preferred by participants and appeared most clear and visible to the participants during the downhill winter sport simulation. Therefore using these colours to display information could help to optimize the optics of a headset display.

The hypothesis for this first scenario was that participants would rank the green icon as having the best clarity and visibility. A secondary proposition was that the red icon would also be ranked high due to its stark contrast. However, the results show that orange was the most preferred color for an icon(mean = 2.91 1.44), over red (mean = 2.94 1.82).

The least visible to the participants was the yellow icon in fourth (mean = 3.5), blue in fifth (mean = 4.0), indigo in sixth (mean = 5.56) and violet (mean = 6.12) which was ranked as the worst overall in terms of visibility and clarity of viewing. The cool blue coloured icons (blue, indigo, and violet) were all ranked as the worst overall in fifth, sixth and last place, which may be a result of participants being visually exposed to sky and snow during the downhill winter simulation, however additional studies would have to be conducted to confirm this proposition.

Icon Location Participants gave each of the five locations a rank, 1 for best to 5 for worst. The subjective results showed that participants selected the top-right icon as the best overall (mean = 2.15 1.05), followed by bottom-right location (mean = 2.53 1.26) and top- left location (mean = 2.74 1.31) in third. Both the middle location (mean = 3.41 1.56) and the bottom-left location (mean =

3.65 1.04) of the test icon were the least desired by participants and were ranked fourth and fifth respectively, with a mean greater than 3.40.

These results suggest that on average, participants preferred viewing icons on the right-hand side of their vision since the top-right location was ranked first and the bottom-right location was ranked second, which could indicate that many of them are right-eye dominant. However, more tests would have to be conducted to confirm this. The top-level locations were ranked first and third, while the bottom-level locations were ranked second and fifth, suggesting that the participants preferred the icons to be located within the top segment of the field-of-view compared to the bottom segment of the field-of-view.

Icon Alert Mode Participants gave each of the four alert modes a rank, 1 for best to 4 for worst. The subjective responses from this study showed that the colour changing icon alert method was ranked best overall (mean = 1.71 1.06), followed by the blinking icon alert method in second (mean = 2.35 0.88), the rotating icon alert method in third (mean = 2.53 1.11) and finally the pulsing icon alert method (mean = 3.41 0.70) was ranked worst overall. The two icon alert methods with a blinking style were ranked first and second in terms of most attention grabbing while also not being overly distracting to the user.

4.2.4. Icon Slope angle indicator - No icon indicator The data from this study showed that for the first, resting angle interval (5) 6 participants (18%) responded with the correct angle, and 22 participants (66%) responded within the range of 0-10). For the second angle interval (14) no participants responded correctly and only 6(20%) participants answered within the range of 11-20. For the third angle interval (20) 2 participant) answered correctly and 4 participants (12%) answered within the range of 16-25. Finally, for the fourth angle interval (9) no participants answered correctly but a total of 12 participants (36%) answered within the range of 6-15 When the platform was at its resting position (5) 18% of participants responded correctly and 66% participants answered within a 10 range, compared to the remaining three angle intervals which has significantly less participants respond correctly or accurately within a 10 range.

The test without using headsets on the slope design showed that participants responded incorrectly without an assistive icon displayed in the AR headsets. The results suggest that it is difficult for an individual to use their visual and spatial awareness abilities to accurately determine the angle of the slope.

5 Discussion

5.1 Visual Interface Design Recommendations

Average participants preferred viewing icons on the right-hand side of their field-of-view, since top-right is ranked first and bottom-right second, which could indicate that many of the participants were right-eye dominant. However, the icons located within top-level icons were ranked first and third, while the icons located within the bottom-level were ranked second and fifth, suggesting that participants on average preferred the icon to be located at the top of the field-of-view compare to the bottom of the field-of-view. This could be a result of easier and more comfortable viewing of an icon located in the top-level, as one participant stated in their post-test comment, "[It was] difficult to change the focal point quickly in the bottom- right, [it was] easier to change focus when looking or glancing to the top-right away from the snow".

Another way to optimize the colour of a display icon would be to ensure that every athlete can read the information clearly by implementing a customization of the icon and allow the end-user to pick the icon colour that works best for them.

Icon alert method used to determine which of the four icon alert methods was most visible and most effective at capturing the participant's attention. The results showed that the icon alert method that was preferred and ranked as the best and most effective overall was the colour changing icon alert (mean = 1.71), followed by the blinking icon alert in second (mean = 2.35), the rotating icon in third (mean = 2.53) and finally the pulsing icon alert method (mean = 3.41) ranked as worst overall.

An icon in the field-of-view of a headset display that combines both colour and a highly detectable but non-distracting blinking effect will likely have a higher rate of detection, which was indicated by the data of the top-ranked, coloured, blinking icon alert method test conducted during the study (See Fig. 11). In conclusion, the results of the visual variable tests are as follows:

- Icon Colour: An icon using orange, red, or green colours that contrast the outdoor winter environment will allow for the best visibility and clarity for the athlete reading the data,
- Icon Location: An icon located in the top level of the field-of-view, and more specifically, the top-right, will allow for the best unobtrusive and natural viewing of the interface,
- Icon Alert Method: An icon that changes colour and blinks in the display will attract the visual attention of the athlete best during a downhill winter sport activity

Recommendations for Physical Design During the post-test survey when participants were asked to indicate if wearing the AR headset and viewing the icon felt natural and comfortable, 8 participants (23%) strongly-agreed, 19 participants (56%) agreed, 7 participants (21%) disagreed and thought that the display was not comfortable and natural and no participants strongly-disagreed. The comfort of the Moverio BT-200TM AR headset that was worn by participants during this thesis study was evaluated, and 79% of participants agreed that the Moverio BT-200TM felt natural and comfortable to wear.

There are a number of ways to increase the comfort of a headset such as reducing the weight, distributing the weight of the headset more evenly throughout the main body of the device, making it more adjustable, and altering the size of the headset display lens giving the field-of-view a larger surface area than standard ski goggles and more space to display an unobtrusive icon with information.

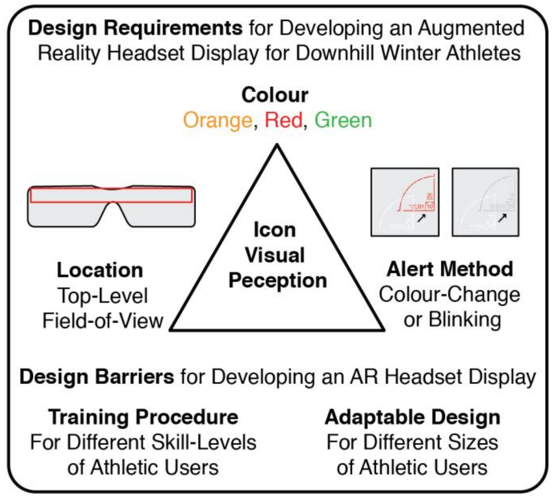

Fig. 11. Design Requirements and Barriers for Developing an AR Display for Downhill Winter Athletes

5.2 Suggestions for Study Improvement

The limitations related to the thesis study can be divided into two different categories; environmental limitations and technological limitations.

The first environmental limitation related to this study was the simulation room temperature of 21C compared to winter temperatures experienced on an actual ski hill. Another environmental limitation was the lack of physical precipitation (snow, rain, etc.) and wind or air pressure during the test. To overcome this wind limitation, participants wore wireless headphones playing realistic wind sounds. However, there was no physical wind sensation.

The lighting within the simulation room was also an environmental error, although some natural light came from windows, mostly overhead artificial florescent bulbs provided white light to participants.

The wireless headphones used to simulate wind sounds were large and bulky and would not be worn in real-life by athletes on the slopes.

The slope changing platform also was problematic because of technological limitations. Firstly, the remote control, electric car jack had a single rate of speed to lower and raise the platform to change its angle during the simulations. The platform required the primary researcher to raise and lower the platform using a remotely using a handheld controller.

As with any simulation training, there were some technical limitations due to the equipment that was available, compatibility of devices within the simulation system, and the current level of technology. The first limitation is the size and weight of the Moverio BT-200TM headset used during this study, which resembles reading glasses, not ski goggles and is weighted on the front with no back strap that ski goggles would have to add extra support.

Another limitation was the AR headset's restrictive field-of-view, which did not allow for an icon to be displayed in the far peripheral edges of the participant's field-of-view. However, it was sufficient for this study. It should be noted that limitations such as these are expected when designing, building, and testing prototypes within a controlled lab environment. Although it is nearly impossible to replicate an outdoor winter environment within a test room the measures that were taken adequately simulated a winter environment for what was required of this research study.

For the duration of this study, only day-light testing was conducted. There was no night- time or low-light testing; however, this could be explored in an entirely separate study.

One final limitation of the slope changing platform was that it simulated only the slope angle changing in one dimension while the participant stood with bent knees. Thus, there was no side to side motion of carving experienced on both skis or snowboard, which would have made the simulation feel more realistic.

6 Conclusion

The primary goal of this thesis study was to investigate the barriers and design recommendations for developing an AR display and icon system for downhill winter athletes. Insights from athlete participants and quantitative results from the simulation testing helped answer the first research question. It was determined that downhill winter athletes could benefit from access to spatial orientation and other important data during an activity.

Participant insights and responses to questions within the post-test survey also helped answer the second research question. Participant comments and responses to questions indicated that the visual modality and augmented reality headset displays were best to transmit unobtrusive data to downhill winter athletes during activity. When asked which of the five senses would be best suited to transmit data to downhill winter athletes during an activity, 27 participants (81%) ranked "sight" as the best-suited sense.

Finally, the inquired data helped to identify the icon colour, location in the field-of-view and visual alert that participants preferred for viewing, and answered the third research question. During testing, participants ranked orange (mean = 2.91), red (mean = 2.94) and green (mean = 2.97) all very closely, which indicated that the participants preferred icons using orange, red or green colours which appeared to contrast the outdoor winter environment and allow for best visibility and clarity while reading the data.

Similarly, participants ranked icon locations from best (1) to worst (5) and ranked top-right first (mean = 2.15), top-left second (mean = 2.74) and bottom-right third (mean = 2.53) which indicated that participants preferred icons in the top level of the field-of-view (more specifically the top right) which seemed to allow for the best unobtrusive and natural viewing of the icon. Participants also ranked alert methods from best (1) to worst (4) and ranked the blinking-color icon (mean = 1.71) and the blinking icon (mean = 2.35) as top two alerts, which indicated that icons which change colour and blink on/off in the display were preferred by participants and appeared to attract their visual attention most effectively during the testing.

Future research directions include (1) validating the results obtained from the simulations used in this study, in an outdoor ski hill environment,(2) exploring if the HMD would provide navigational instructions relative to the orientation of the head, (3) evaluating the downhill winter athlete's ability to interpret the icon while in a competitive scenario, (4) utilizing the augmented reality headset system and slope changing platform designed specifically for this study, to evaluate the visual perception and spatial awareness of different types of athletes.

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