

**Enhancing Winter Sport Activities: improving the visual perception and spatial awareness  
of downhill winter athletes with augmented reality headset displays**

by

Darren O'Neill

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## ABSTRACT

Strong spatial-awareness and visual perception skills can improve an athlete's performance, enhance training routines and reduce the potential for injury due to physical error. This research study looks to investigate the barriers and design requirements for developing an augmented reality headset display for downhill winter athletes, which may improve visual perception, spatial-awareness and reduce injury. This research used a variety of human-centred-design methods to collect the participant data, including surveys, experience-simulation-testing, user-response-analysis, and statistical analysis. During the study, 34 participants with previous experience skiing, or snowboarding at different skill-levels, wore an augmented reality headset and evaluated the visual perception of an icon, while watching a simulation video and standing on a slope changing platform to simulate a downhill skiing experience. The study revealed that various levels of downhill winter athletes may benefit differently from access to athletic data during a physical activity, and indicated that some expert level athletes can train to strengthen their spatial-awareness abilities. The results 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, visual perception, spatial-awareness, human-centred-design

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## PREFACE

All my life I have always been very active in both sports and outdoor activities, and I grew older I became more involved in extreme and alternative sports, primarily snowboarding and skateboarding. During my post-secondary studies at Carleton's School of Industrial Design, I became more interested in the design and manufacturing of wearable technology and the potential applications that these devices could have in the extreme and alternative sports industries. I would often purchase various wearable devices, many intended for use while jogging, cycling or working out, and proceed to test them while participating in an alternative sport like snowboarding or skateboarding to evaluate how the device performed. I started to think how wearable devices could be utilized by extreme athletes who participate in high-risk, high-pressure sports to optimize athletic training, increase athlete safety and reduce the potential for injury. As a designer, I want to participate in the early stages of the design process, working with end-users to test and to integrate new and emerging technologies into products, that will help to enhance human experiences and improve quality of life. I wish to utilize new technologies with specially designed athletic devices to help athletes reduce sport-related accidents and injury, improve productivity and maximize the overall enjoyment of physical activities.

## 1.0 INTRODUCTION

For downhill winter athletes, there is a need for enhanced visual perception and physical awareness during a physical activity, which can be the factor that makes the difference between a successful run and a failure. In the past, downhill winter athletes have, “underlined the importance of visual perception for optimal performance, even though they seem to rather unconsciously pick up visual information during races,” (Schläppi, Urfer & Kredel, 2016, pg. 203). In all sports and athletic activities, the risk of injury can be decreased and competitive performance level increased, by improving visual perception and spatial awareness through training methods or by using assistive devices.

Over a 12-year period, “a total of 4,083,691 injuries were reported for all 7 extreme sports between 2000 and 2011” (Sharma, Rango, Connaughton, Lombardo & Sabesan, 2015, pg. 3) with the 7 sports identified in the study as; snowboarding, snowmobiling, surfing, mountain biking, motocross, skateboarding, and snow skiing. During the same 12-year period, “a total of 460,115 recorded bodily injuries were head (83%) and neck injuries (17%)” (Sharma et al., 2015, pg.3). Although some bodily injuries experienced by extreme athletes are not serious and can be treated with a little rest and rehabilitation, other injuries are more severe and could cause spinal cord or brain damage resulting in permanent physical impairment, paralysis or even death. For many athletes, especially extreme and alternative sport athletes, the difference between success and a failure that could result in injury can be a split-second mistake, or a momentary lapse in attention. Wearable devices, and more specifically augmented reality headsets, that display unobtrusive, spatial orientation and location data to athletes could potentially improve an athlete’s visual perception and awareness during an activity. This increased awareness could

potentially improve success rates and reduce the likelihood of failure and injury, however this needs to be explored.

Wearable devices have become increasingly more prominent in modern society, being used by coaches and medical professionals, to monitor and to communicate biometric information back and forth, with athletes and patients during training or rehabilitation. Wearable devices are often associated with the term “digital health” which encompasses “telehealth systems, mobile health applications and devices, sensor-based technologies, big data and predictive analytics, chronic care management, genomics, wearables, and wellness and fitness devices” (Schüll, 2016, pg.1). When used in sports, various sensors embedded in the wearables devices, “provide coaches and athletes with performance data shortly after motion execution” (Baca, Dabnichki, Heller & Kornfeind, 2009, pg. 1341) for quick viewing or further analysis through a designed network. The collected and analyzed data can then be reviewed by the coach and athlete later, or transmitted to the athlete during the activity, in real-time, through visual, auditory, or tactile formats depending upon user preference. For downhill winter athletes who travel at high speeds, down cold and windy ski hills with varying types of terrain, any additional information on their location, orientation, speed and other biometric variables, such as heart rate, could potentially help to improve an athlete’s visual and spatial perception during the activity.

## **1.1 Rationale and Purpose for the Study:**

The main purpose of this research study is to investigate if downhill winter athletes can benefit from access to spatial orientation and other important biometric data while participating in a physical activity, and how to best display this information to the athlete. Currently, athletes who participate in sports like running and cycling are already utilizing wearable devices, such as wristbands and in some cases headset displays, to read biometric data during and after performing a physical activity. These devices have been designed and tested for a specific market segment of athletes to use in a specific context of activity, and often do not translate well to be used during other more alternative sports, such as downhill winter sports like snowboarding and skiing. This study also looks to determine how sensory modalities (sight, smell, touch, taste and hearing) paired with technologies are best used to transmit unobtrusive data, in a format for effective utilization by downhill winter athletes during an alternative sport activity. Although there is currently literature on developing and evaluating augmented reality headsets for entertainment purposes (video games and movies) and standard sports (such as running or cycling) there is no literature on the design specifications for headset displays developed specifically for downhill winter athletes. Currently, some of the big sport equipment manufacturing companies, such as Oakley and Recon Jet, have conducted in-house research and development in this sector and have started to manufacture consumer products with augmented reality visual displays, however none of this research is ever published or available to the public. Due to this gap in the literature, this thesis study looks to investigate the optimal format, technologies and sensory modalities that can be utilized to transmit unobtrusive information on biometrics and spatial orientation to downhill winter athletes. Since excellent visual perception, dynamic visual acuity, and quick reaction times to visual stimuli are proven to be essential to the

success of high-level athletes, a wearable headset could likely deliver essential information most effectively to the athlete while not being overly obtrusive and distracting during physical activity. A wearable headset could provide coaches, trainers and medical professional the ability to better monitor the athlete's biometrics, location, speed and other important factors through the eyes of the athlete in real time, allowing for quick review and analysis on the fly.

## **1.2 Research Question**

This thesis study looks to investigate the barriers and design requirements for developing an augmented headset display for downhill winter athletes, which may improve visual perception, spatial awareness and reduce the potential for injury.

- To investigate if downhill winter athletes can benefit from access to spatial orientation data and other important athletic information during a physical activity;
- To determine how sensory modalities and technologies can be integrated to transmit unobtrusive data to the athletes; and
- To evaluate what visual format is the most effective to deliver the data to the athletes.

## **1.4 Contribution to the Field**

The results and findings of this study contribute to the educational fields of Industrial Design, Computer Human Interaction (HCI), and Cognitive Psychology. Recent advancements in augmented reality devices have led researchers to conduct studies to test the feasibility of utilizing augmented reality to enhance or improve a variety of activities in a range of different environments and contexts. There currently are no scholarly research studies on the use of augmented reality headset displays in the context of downhill winter sports, therefore this study

could give valuable insights into the subject and potentially lead to future research. Unlike, “other sports, where gaze registration techniques have been extensively used to examine the role of visual perception, up to now, it does not seem possible to reliably measure gaze behavior under the extreme conditions of high-speed skiing,” (Schläppi et al., 2016, pg. 201) therefore it is difficult to conduct research on the visual perception of downhill winter athletes due to these technical limitations. If the research study is not conducted in a real-world environment, then the extreme conditions of high-speed skiing or snowboarding must be simulated effectively for the research to be accepted as valid. The results of this study could lead to insights and design principles to help optimize the display of information for downhill winter athletes, while utilizing principles from the fields of Industrial Design, Computer Human Interaction and Cognitive Psychology. This research could also contribute to the design of head-up-display systems for other sports and athletic activities or for any activity that requires precise visual and spatial awareness to achieve a specific goal, for example medical surgeries or construction projects.

## **2.0 LITERATURE REVIEW**

The following literature review is a combination of scholarly journal articles, thesis dissertations and conference papers on a range of topics including athletes, augmented and virtual reality devices, spatial awareness, visual perception principles and participatory design. The literature describes the importance of spatial awareness and visual perception to athletes and shows that, “in recent years, more emphasis is laid on applying the augmented reality in various sports branches, competition broadcast and implementation of sports education” (Bozyer, 2015, pg. 316). Literature analysis revealed how virtual and augmented reality devices can be designed and utilized to enhance a downhill winter athlete’s visual and spatial abilities, and how the athletes must be a participant in the participatory design process to reach an informed design result.

### **2.1 Wearable Devices**

Over the last decade, wearable devices, “comprising devices whose embedded sensors and analytic algorithms can track, analyze and guide wearers’ behavior – have increasingly captured the attention of venture capitalists, technology start-ups, established electronics companies and consumers, “(Schüll, 2016, pg.317). Virtual reality (VR) and augmented reality (AR) headsets can be classified as a wearable device but are used mainly being used to facilitate a more immersive entertainment or video game experience. However, VR and AR headsets are not just excellent entertainment devices. If effectively implemented into the sports industry they have the potential to improve athlete training, reduce physical error, prevent serious injury and allow for constant athlete monitoring. Currently, the type of wearable devices used by athletes can be classified as personal informatics systems, which are a set of systems that serve as persuasive tools and, “help people collect and reflect on personal information” (Li, Dey, & Forlizzi, 2010,

pg.557). These systems and related products primarily focus on making the user aware of themselves, by providing biometrics and personal information usually during some form of physical activity, while also motivating them to participate in healthy activities more frequently. After capturing and analyzing biometrics, the system makes suggestions to improve the user's daily lifestyle and, "to 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, informatic mode of perception" (Schüll, 2016, pg.235). Personal informatics systems are often designed as holistic activity managing systems which are, "more advantageous as these are combined versions of pedometers, accelerometers and heart rate monitors, some of which also have mobile applications" (Kuru, 2012, pg.15) which are used to constantly monitor and communicate with the user during the duration of a physical activity.

Many new and emerging ubiquitous computing developments have allowed for the miniaturization of important technological components such as; basic sensors (to measure force, torque, pressure, acceleration, velocity), position detection sensors (Global Positioning Systems), motion detection sensors (gyroscopes), equipment monitoring sensors (load force and stress), and physiological sensors (heart rate) (Baca et al., 2009). These sensors can be utilized to acquire, analyze and present performance data without affecting the athletes during training and competitions, by presenting the data to the athlete or coach via computational devices, such as smartphones or AR headsets, after it has been analyzed. Current applications of wearable sensor technologies can be found in; analysis systems (capture the kinematic motion of athletes), coaching systems (real-time monitoring with immediate feedback), decision systems (sensors evaluate competitions to comply with rules) and entertainment systems (measure activities to

make more entertaining) (Baca et al., 2009). The information received from these sensors and displayed on the computational devices can be used to track athlete training progress over time and determine how much the athlete has improved, set numerical training goals, and focus in on the statistics from successful runs, so the approach and results can be replicated.

### **2.1.1 Virtual Reality**

Virtual Reality (VR) is defined by the Merriam-Webster's Collegiate Dictionary as, "an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment" meaning the user is fully immersed in a virtual environment. In an attempt to deliver an engaging VR experience to the average consumer, many of the large and powerful technology corporations such as Microsoft, Samsung and Google have designed and manufactured their own, more economical VR headsets. Some of the more advanced VR headsets such as the Oculus Rift™ and HTC Vive™ are specifically designed to enhance the video game experience and are expensive because they have more immersive features. For example, the final version of the Oculus Rift™ (valued at approximately \$600 USD), "offers built in audio, full 360-degree motion tracking, and asymmetric lenses which help to maximize the field-of-view (FOV) and image quality" (Gradl, Eskofier B., Eskofier D., Mutschler & Otto, 2016, pg.886). The HTC Vive™ (valued at approximately \$800 USD) has very similar features, but additionally, "offers a tracking area of 4.5 square meters for the user to move around and interact with virtual objects while using motion-tracked, haptic controllers" (Gradl et al., 2016, pg.886) unlike the Oculus Rift™, which is used while seated. On the other end of the consumer VR spectrum are cheap alternatives like the Google Cardboard™ and Samsung Gear VR™ headsets (both valued at

approximately \$30 USD), which each utilize, “a smartphone with a high-resolution screen and dedicated sensors to provide an untethered VR experience” (Gradl et al., 2016, pg.886).

Consumer VR headsets are great for entertainment purposes, however only one consumer (the HTC Vive™) provides an accurate but limited position tracking which is required by athletes who must move around within a large designated area. This is a big requirement that VR headset designers and manufacturers must work to overcome, to allow users the freedom to move within a much larger tracking area. Another challenge that designers of VR headsets must overcome is acceptance within the sport industry, as many athletes have never used or even considered using VR headsets for training purposes. Gradl et al. (2016) noted from an online survey with 227 athlete participants that despite most participants not knowing about virtual or augmented reality beforehand, the majority were still inclined to use it after being confronted with possible usage scenarios. This means that although most current athletes have never used any sort of wearable headset device in their daily lives, after learning more about the technologies they can see the potential in using these devices to improve training routines and elevate their performance level.

### **2.1.2 Augmented Reality**

Augmented Reality (AR) is defined by Merriam-Webster as, “an enhanced version of reality created by the use of technology to overlay digital information on an image of something being viewed through a device, such as a smartphone camera” meaning virtual elements are overlaid in a real-world environment, in real-time. Head-up-displays are less advanced versions of AR displays designed to transmit information, and are defined by Oxford English Dictionary as, “a display of instrument readings in an aircraft or vehicle that can be seen without lowering the

eyes, typically through being projected onto the windshield or visor”. Instead of exploring virtual reality, some tech companies have invested in designing and producing consumer level, AR headsets for use in a real-world context as opposed to an entirely virtual world. Another well-known consumer headset is Google Glass™, an AR headset which lacks eye-tracking, but is instead designed specifically to provide information to the user at the periphery of their vision, while they view the real-world environment (Kotsios, 2015). Unfortunately for Google Glass™, “privacy concerns were raised both for the user of the device and also for third persons who are part of the environment of the device, namely persons whose image can be captured and therefore digitized by the wearable AR device” (Kotsios, 2015, pg.163) and because of this the device was never brought to market.

Oakley, a global leader in active eyewear technology, recently designed and manufactured high-definition optic ski goggles with an unobtrusive prism lens located in the bottom right edge of the frame, which digitally displays real-time information to the athlete. The Oakley Airwave™ goggles (Figure 2-1, left), valued at approximately \$600 USD, use an integrated GPS to calculate speed, altitude, vertical descent and navigation (including maps for many ski resorts, accurate to within a meter), and a three-axis accelerometer and gyro sensors to analyze jump distances, height and air time (Vintar, 2013). The goggles can also pair with smartphones via Bluetooth for complete control over music playlists, texting and calling giving it all the essential functions that any skier or snowboarder would require while riding (Vintar, 2013).

Another sport industry taking advantage of augmented reality headsets and visual displays is the cycling industry, for use by both competitive and recreational cyclists. Recon Instruments is a

Canadian company that has developed the Recon-Jet™ smart-glasses (Figure 2-1, right) and was recently purchased by Intel for \$175 million (Cooper, 2015). The Recon-Jet glasses sell for \$699 USD which are essentially sunglasses with an integrated micro-processor and various sensors, specifically designed for cyclists or long distance runners to monitor their speed, cadence, distance travelled, calories burned and more (Cooper, 2015). All the computational components, including the camera, GPS, charging port, controls and the small visual display placed under the eye, are all situated on the right side with the battery on the left side to evenly distribute the weight (Cooper, 2015). Although the Recon Jet is a great example of augmented reality headsets being utilized in a high speed, athletic context, in a recent online tech review for engadget.com, the reviewer Daniel Cooper pointed out some issues he encountered. One of the more noticeable issues is the bulky design making the headset heavy and at times uncomfortable to wear, another issue was the location of the mounted display causing discomfort and making it difficult at times to glance down at the information (Cooper, 2015). These AR headset examples illustrate how technological corporations and eyewear manufacturers are using augmented reality headsets to deliver an elevated experience to the end user, in an attempt to improve the overall activity whether it be playing video games, or participating in an athletic sport.



*Figure 2-1. Oakley Airwave Goggles (left) and Recon Jet Cycling Glasses (right) (Google)*

Bozyer (2015, pg.317) defined augmented reality (AR) as, “the technologies developed for increasing the perceptions by transferring more information and data to people about the real world which they perceive through their senses”. Virtual reality (VR) fully immerses the user wearing the high-resolution display headset in a 3D virtual environment, while AR headsets allow the user to view the real-world environment overlaid with visual icons and data to display important information. Typically, most augmented reality applications designed for sports focus on the development of expert systems which, “concentrate on development of expert systems which will substitute or facilitate the training of sports people and help the trainers or on managing competitions in a more fair way and presenting the competitions to audiences in a more entertaining and attracting way” (Bozyer, 2015, pg.318). Over the past few years the number of, “mobile AR prototypes (MAR)” (Bozyer, 2015, pg.317) and applications, such as the smartphone game Pokemon Go™, have increased allowing individuals to experience different levels of AR through the screens of their very own smartphones. These MAR smartphone applications are developed specifically for a modern smartphone which utilize a high-resolution camera and gyroscope, accelerometer and Global Positioning System (GPS) sensors, allowing the device to accurately determine its exact location and spatial orientation in the real world. The smartphone’s camera, various sensors and cloud computing power allows for the MAR application to scan and identify objects or elements within the environment, in real-time and display the information back to the user in their visual field (Delabrida, D’Angelo, Oliveira & Loureiro, 2016). For example, in a recent study by Delabrida et al. (2016) a Samsung Galaxy™, smartphone was integrated into a wearable, 3D printed, head-mounted-display (HMD) so that various sensors could be used for distance measuring between objects in the field of view, and weather monitoring during ecological field research trips.

Over the past decade the medical industry has also been developing AR headset prototypes and test head-mounted-display (HMD) systems in clinical simulations to assist in the removal of cancerous tumors which requires extreme precision and accuracy. Neurosurgeons have also developed and tested a head-mounted, AR goggle system to augment brain tumor boundary lines precisely on the spot where the tumor is located, allowing the surgeon to track the end of the tools and eliminate the need for a fixed monitor display (Azimi, Doswell & Kazanzides, 2012, pg.123). In another study, researchers developed, tested and compared two different modes of a wearable augmented reality system (head mounded display HMD and Google Glass™) to assist in the intraoperative imaging of surgical margin in cancer resection surgery (Shao, Ding, Wang, Liu, Ling, Chen, Xu J., Zhang & Xu R., 2014, pg. 2228). The results propose a surgical navigation system that combines the sensitivity and specificity of a fluorescence imaging system and the mobility of a wearable goggle technology, which can potentially be used by a surgeon to identify the residual tumor and reduce the risk of recurrent diseases without interfering with the regular resection procedure (Shao et al., 2014, pg. 2236). By using this AR goggle system during surgery this would, “reduce the line of sight problem (because the tracker’s line-of-sight is the same as the surgeon’s), the difficulty in association of preoperative images, and the bulkiness that exists in the current systems” (Azimi et al., 2012, pg. 124). These examples from the medical industry illustrate how wearable augmented reality goggles can be used to accurately pinpoint precise locations for surgery and improve or enhance the surgeon’s visual perception allowing them to perform the task more efficiently.

By linking a smartphone and a wearable AR headset via a specifically designed MAR application, the user can now view the external environment through a hands-free, augmented

lens which displays important information and data during an activity. When designing AR systems and associated interactions it is important to remember basic Human-Computer-Interaction (HCI) design principles developed to help aid and improve the design of computer and smartphone applications. Various HCI design principles found in the literature can be interpreted to better design AR headsets such as; system affordances, reducing cognitive overload, reducing physical effort, system learnability, user satisfaction, flexibility in use, responsiveness and feedback, and error tolerance (Dünser, Grasset, Seichter & Billingham, 2007). Some key considerations for developing safe mobile AR or headset interactions, especially for extreme athletes utilizing AR headsets include, “not disturbing the user’s behavior with virtual object and allowing freehand interaction” (Ishiguro & Rekimoto, 2011, pg. 1). 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 important objects in the external environment like signs, lights, and large obstacles such as trees and rocks. (Ishiguro & Rekimoto, 2011, pg. 4) By using basic Human Computer Interaction and augmented reality design principles, user-friendly headset devices can be developed to enhance human abilities and provide visual assistance to the user in a variety of different contexts.

### **2.1.3 Augmented and Virtual Reality Simulation Training Systems**

More recently, complex VR systems are being designed and custom built, to train and evaluate certain types of athletes in specific sport events. For example, Stinson & Bowman (2014) developed and tested a VR system for athlete psychology training, which utilizes a virtual soccer goalkeeper application to trigger anxiety in participants, preparing them for high-pressure real world situations. In another study, a team of researchers developed an immersive VR tennis

education system, by utilizing new and emerging technologies such as a High-Definition (HD) stereoscopic two wall display, accurate hybrid motion tracking, haptic (vibrational) feedback, and intelligent character animation control to achieve a real-time tennis experience for participants (Song, Xu, Fong, Chin, Chua & Huang, 2012). Training systems can utilize varying levels of VR/AR to simulate realistic training conditions allowing athletes to train in a more safe and controlled environment with realistic situations that focus on simulating the weather, time pressure, visuals and gravitational forces (Song et al., 2012, pg. 1324).

Currently, there are some examples in the literature of custom designed ski-simulators, with varying levels of VR/AR, that help the user to train and improve their balance, without the need to train in the real environment. A South Korean manufacturer developed an augmented reality (AR) ski simulator, which was tested by 7 national team-level athletes from “K” Sports University in South Korea, who evaluated the effectiveness of the simulator, which utilizes 3 digital video cameras and a wireless electromyography system to perform 3D motion analysis and measure the athlete’s muscle activation level (Moon, Koo, Kim K., Shin, Kim H. & Kim J., 2015). The results from that study showed that hip angulation increased as the frequency of ski turns increased, indicating that training using an AR ski simulator results in movements that extended the lower body joints, which can increase muscle fatigue and result in a better workout. (Moon et al., 2015 pg. 2630). The study also found that, “ski athletes could use the simulator to maintain their functional and strength capabilities for skiing, especially during a non-ski training period like summer” (Moon et al., 2015 pg. 2632). In a similar study, an alpine ski simulation, training system was utilized to attempt to evaluate the impact of visual 3-dimensional perception and simulated weather on the results, by introducing visual weather effects like fog snow and

rain, to make the simulated course more real and difficult for the professional alpine ski participant to navigate (Aleshin, Afanasiev, Bobkov, Klimenko, Kuliev & Novgorodtsev, 2011). In a study conducted by Lee, Roh and Kim (2014), 77 children (placed into a normal or an overweight group) compared a 3-minute Pro Ski-Simulator exercise to the Harvard step-test to evaluate heart rate and endurance by calculating post-exercise recovery rates. Although this Pro Ski-Simulator had no AR/VR element to it, the exercise apparatus helped to improve balance and provide resistance to strengthen muscles, and indicated that the, “Ski-Simulator exercise can produce a cumulative load even when performed at low intensity, which can be effectively used as an exercise routine” (Lee et al., 2014, pg. 641). These examples illustrate that using simulation technologies, accompanied with a well-designed work-out apparatus can benefit the athletes and improve training routines while reducing the cost and risks of training in the real environment.

AR workout systems have also recently been utilized by the medical and physical rehabilitation communities to help improve balance, flexibility and lower body function for the elderly and individuals in need of physical rehabilitation. In a related study seeking to determine what effect AR based exercises have on balance and muscle strength, researchers divided elderly female participants into 3 groups (AR application group, yoga instructor group, and self-exercising group) and gave each group 12 weeks of the same exercise lessons to perform (Lee, J., Yoo & Lee, B., 2017). In a similar study, researchers developed a 3D-AR system to assist the elderly in improving lower extremity function and balance, and had 18 elderly participants test it by playing 3 different AR games designed to focus on specific exercises (hip flexion and internal/external hip rotation to touch in a falling balloon game; flexion and extension of the knees to avoid obstacles in a cave game; and standing on one leg during in specific location

during a rhythm game) (Im, Ku, Kim Y., Cho S., Cho Y., Lim, Lee, Kim H. & Kang, 2015). In both research studies, the results indicated that AR based exercises can improve muscle strength, balance and other physical factors, as participants who used AR showed clinical improvements in the lower body, better joint flexibility, improved standing balance and higher test success rates. The studies indicate that AR/VR assisted training is not exclusive to high-level athletes, as AR/VR systems have the potential to be specifically designed to suit any type of user and optimize their exercises, whether the user is a child, adult, elderly person, professional, or amateur athlete.

Although some athletes may initially be hesitant to train in a VR environment, there are some key benefits to VR training when compared to real-world training. First, “the weather in a VR environment can be easily manipulated” (Song et al., 2012, pg. 1324) to distract the user and increase, or decrease the difficulty of the activity. Second, the variables or, “feelings playing a game can be simulated and changed (gravity, ball speed, spin etc.)” (Song et al., 2012, pg. 1324) to similarly increase, or decrease activity difficulty. Thirdly, within the VR environment, “everything can be precisely measured and replayed” (Song et al., 2012, pg. 1324) for analysis and repetitive training, which is essential for coaching and setting workout goals. Although VR systems are excellent for training athletes in specific repeatable aspects of sport activities (practicing a tennis swing, a soccer kick, a hockey shot etc.) they can often be complex to develop and expensive to construct, usually requiring the integration of new technologies.

## **2.2 Spatial Orientation and Awareness**

The “Spatial Orientation First” principle has been tested in various research studies, and indicates that “when balance and orientation are under threat there is a natural imperative to withdraw cognitive resources allocated to secondary tasks and redirect them to regaining orientation and stability” (Gresty, Golding, Le & Nightingale, 2008, pg. 105). This means that while the individual is trying to regain balance and correctly orient themselves some of their secondary cognitive or physical tasks may be discontinued, or suffer a reduction in performance until balance is regained (Gresty et al., 2008, pg. 105). Some athletes may experience disorientation during an activity or while in the air and lose track of their current spatial orientation in the environment, causing the individual to fall and potentially get injured. The “Spatial Orientation First” principle stems from the “Posture First” principle which was originally developed within the context of bipedal balance, but was then extended to the operation of vehicles such as planes, cars, bikes and more (Gresty et al., 2008, pg. 105). The “Spatial Orientation First” principle therefore applies to many classifications of athletes participating in a wide range of sport activities, including downhill winter athletes.

### **2.2.1 Extreme Athletes and Spatial Orientation**

Extreme sport athletes differ from standard athletes, because they participate in a category of extreme sports which can be defined as “leisure activities where the most likely outcome of a mismanaged mistake or accident is death” (Brymer & Schweitzer, 2012, pg. 477). Although standard athletes who participate in popular mainstream sports and activities like jogging, biking, soccer, and baseball still experience injury, these injuries are often not life threatening and the athlete can return to the sport after a period of rest and healing. But due to many factors that

extreme sport athletes experience such as harsh environments, large vertical drops, high speeds, and performing complex and often dangerous aerial maneuvers, the likelihood that they experience a fatal injury is much higher (Brymer & Schweitzer, 2012). Popular extreme sports with very high risk factors include, “BASE jumping (Buildings, Antennae, Span, Earth – jumping), extreme skiing/snowboarding, waterfall kayaking, big wave surfing, solo free-rope climbing and high-level mountaineering” (Brymer & Schweitzer, 2012, pg. 478). Other alternative sports, such as skateboarding, BMX biking, surfing, mountain biking and wakeboarding still fall into the extreme sport category but are classified as slightly lower risk because the activities performed are “on at a level where death would be rare or nonexistent” although injury is still a factor (Brymer & Oades, 2009, pg. 116). Many of the high-risk, extreme sports such as, “freestyle skiing combine aerobic and balance skills, and participants use a variety of natural and man-made features (such as terrain parks and rails) to perform aerial tricks and maneuvers” (Langran, 2012, pg. 38). Extreme athletes and more specifically downhill winter athletes must therefore practice and train their spatial awareness skills to be able to orient themselves and land successfully after completing an aerial maneuver. For both high-risk and low-risk extreme sports, the difference between a successful run and a run with a physical error which could cause an injury, often results in a split-second decision made by the athlete.

Although all high-level athletes experience some form of stress and anxiety prior to and while performing a specific activity, extreme athletes are forced to frequently experience and overcome feelings of anxiety, fear and stress while they are performing high risk activities. Over time, many extreme sport athletes develop and practice strategies to deal with these emotions until, curtailing fear is no longer a conscious decision but an automatic response (Elias and Dunning,

1986). Meaning that because these extreme athletes have had to confront and overcome fear, stress and anxiety so often during their athletic careers that the process has become almost instantaneous or automatic, and they often do not even think about it. Technological devices are often used to monitor important biometric variables during activity (heart rate device like FitBit), to energize themselves before an activity (playing music in headphones), or orient and direct themselves which reduces uncertainty and anxiety (smartphone maps and GPS tracking). Although extreme athletes are constantly subjected to intense emotions, studies on anxiety indicate that while extreme sport participants are generally less anxious than the average population, emotions of anxiety and fear are experienced by the participant during the activity (Robinson, 1985). This could be because extreme athletes experience intense feelings of anxiety, fear and stress so frequently they have become accustomed to noticing and effectively dealing with these unwanted emotions before they negatively affect their athletic performance. By choosing to participate in extreme sports, extreme athletes are deciding to personally challenge themselves, and to learn how to cope with fear, anxiety and stress in high-risk or high pressure situations, which can lead to a sense of accomplishment.

### **2.2.2 Military Aircraft Pilots and Spatial Orientation**

Aircraft pilots, and more specifically military aircraft pilots who frequently perform aerial maneuvers and travel at extremely high speeds, must always remain visually and spatially aware of their surroundings during flight. Some military pilots frequently experience disorientation and symptoms of vertigo, nausea and dizziness which are caused by unusual vestibular stimulation during flight, and can lead to fatal crashes (Gresty et al., 2008, pg. 106). A recently study revealed that, “over a 20-year period, from 1993 to 2013, the U.S. military has experienced 72

Class A aircraft mishaps involving spatial disorientation (SD), out of a total 601 class A mishaps resulting in the loss of 406 lives, 368 aircraft, and a total loss of \$13.04 billion due to property loss or medical costs” (Poisson & Miller, 2014, pg. 919). After analysis of the compiled data using a variety of methods, the researchers determined that spatial disorientation flight mishaps were caused by four main factors: the type of aircraft involved, single-seat compared to multi-seat aircrafts, the time of day when the mishap occurred, and the pilots level of fatigue (Poisson & Miller, 2014, pg. 920). Since all humans can experience disorientation, some downhill winter athletes that perform aerial maneuvers against the force of gravity may also be susceptible to disorientation and symptoms of vertigo, nausea and dizziness while rotating in the air. Much like the military aircraft pilots in the study, a downhill winter athlete’s visual and spatial perception may also be negatively affected by the time of day (night/low light) and physical fatigue while participating in a high-risk activity, which can lead to athlete error and possible injury.

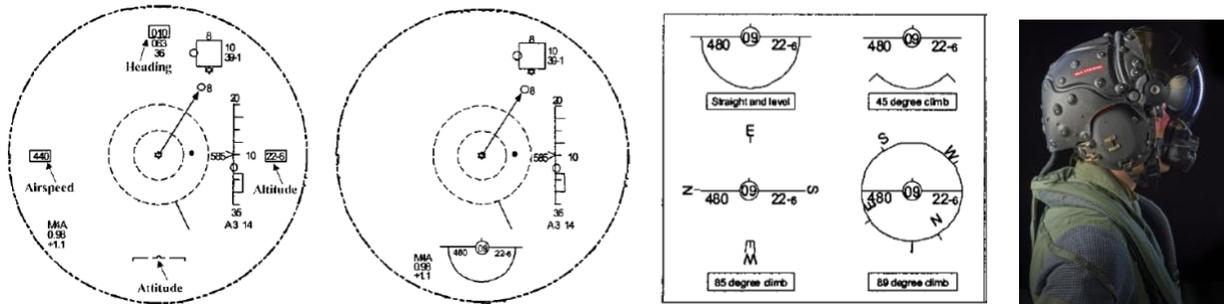
Pilots will often have to determine an aircraft’s orientation with visual flight instruments which, “involves considerably greater conscious cortical processing than when flying with the aid of external, ambient visual cues” (Gresty et al., 2008, pg. 105) such as trees, clouds or mountains. Similarly, downhill winter athletes use visual cues such as trees, or flags on jumps or race tracks to remain balanced and on course, as demonstrated in a recent study where downhill alpine skiers identified that, “gaze patterns include visual cues, which are related to the slope, the gates, and the visual background” (Schläppi et al., 2016, pg. 211). Both military aircraft pilots and extreme downhill winter athletes have many similarities, which may indicate why AR headsets and principals utilized by military pilots could also be utilized to benefit downhill winter athletes. Both military pilots and downhill winter athletes have naturally good spatial awareness abilities

and experience higher than normal levels of anxiety and stress but are trained to cope with it more effectively. Both professions require extensive training prior to high-level participation, and are usually trained by expert coaches or by using some form of VR/AR simulation to minimize risk to the trainee (ex. flight simulators and downhill ski simulators). Finally, both downhill winter athletes and aircraft pilots are concerned with monitoring similar variables during participation, including speed, acceleration, altitude, G-force, vertical and horizontal orientation, directional heading, and important biometrics such as heart rate and breathing. These variables are being monitored by not only the participant (the athlete or the pilot) but will also be monitored by some sort of training personnel (athlete coaches or mission control) to ensure participant safety and success.

### **2.2.3 Spatial Orientation Devices for Military Aircraft Pilots**

An excellent example of a complex HMD system used by military pilots is the Spatial Orientation Retention Device (SORD) composed of, “a tactile vibrating vest, a helmet-mounted visual display and 3D audio headphones” (Albery, 2005, pg. 5) developed and tested by the U.S. Department of Defense. 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 cock-pit displays and controls (Albery, 2005). It was found through extensive research that HMD symbology (Figure 2-2) used by pilots, “should be designed to support an efficient instrument scan, support other mission related symbology, and utilize as little of the display FOV as possible” (Geiselman, 1999, pg.

1964). Similar HMD icon design principles used by the military could potentially be utilized when developing an interface to support efficient variable scanning for downhill winter athletes, because they too require spatial orientation data and other biometric information.



*Figure 2- 2. Icons Used by Military Aircraft Pilots (left) During Flight (Geiselman, 1999) and a Head-Mounted-Display (right) Used by Military Pilots (Google Images)*

### 2.3 Visual Perception

When designing icons and interfaces to be displayed by a visual screen, it is important to consider the basic laws of visual design, including the Gestalt Principles. Many of the well-known and established Gestalt principles related to the visual perception of 2-dimensional images can be translated and applied to modern day digital screens. In a study on Gestalt theory in visual screen design, Chang, Dooley & Tuovinen (2002) list the key Gestalt principles to consider as balance, continuation, closure, figure-ground, focal point, isomorphic correspondence, good form, proximity, similarity, simplicity and unity. These Gestalt principles used in collaboration, are thought to improve educational screen design and participant learning, because, “the user evaluations indicate that all the identified Gestalt laws are beneficial for visual screen design and learning effectiveness” (Chang et al., 2002, pg. 8). When designing dynamic icons for augmented reality headset displays, the Gestalt principles adapted for visual screen

design should be utilized and carefully balanced to develop an interface that is simple and easy to read, efficient to use and effective in assisting the user to complete the desired task.

The colour and opacity of elements, or icons within visual displays, especially head-mounted displays, can also affect the visual perception of the person utilizing the display. Different colours of visual elements can also benefit the user depending on the context or the environment that the display is being used in, for example; indoor vs. outdoor lighting and day time vs. night time. In the past, aircraft pilots utilized heads-up-display (HUD) projectors which generate “a green wavelength of light (545 nm) which falls around the peak of the human eye’s photopic response indicating that this colour is generally the most effective for viewing” (Nicholl, 2014, pg. 7). Today’s modern HUD systems use light-emitting-diode (LED) light sources and a liquid-crystal- display (LCD) screen which allows for even greater wavelength specification, and adjustment of contrast and background lighting (Nicholl, 2014, pg. 7). Although there is some literature on the optimal icon colour of HUD displays for pilots, there is currently no literature on the colour testing and development of headset displays for downhill winter athletes.

### **2.3.1 Visual Perception Tests for Athletes**

Visual perception tests utilizing both analog instruments and digital devices have been used as tools for studying the visual abilities of participants, to test how different environments or participant skill levels affect the visual perception of a stimulus. In a previous study, Ishigaki and Miyao (1993) compared the dynamic visual acuity of 53 athletes and 46 non-athletes using a circular target. The target moved left and right on a screen initially at maximum velocity and then gradually slowing until the student correctly recognized the direction of the gap in the ring,

which was used as the measure of visual acuity. The results indicated that the dynamic visual acuity of athletes is superior to that of the non-athletes, because when the gap was 42' and 28' in size there were no differences in the performances of the two groups, but when the gap was 14' and 8' athletes could recognize the gap at significantly higher velocities than the non-athletes (Ishigaki & Miyao, 1993, pg. 835). In a similar but more recent study by Zwierko (2008) the peripheral perception of 16 athletes (handball players) and 16 non-athletes was tested using the Vienna Test System, which consisted of participants seated facing forwards while flashing vertical lines appeared in the peripherals (40 on the left and 40 on the right for a total of 80 lines) prompting the participant to react by pressing a foot pedal. The results showed that basic peripheral vision functions with regards to field of vision, width, and correctness of reaction to stimuli did not differ between athletes and non-athletes, "however athletes had a significantly shorter response time to stimuli appearing in the peripheral field of vision compared to non-athletes" (Zwierko, 2008, pg. 60). In a cross-sectional observation study, elite motorsport athletes and sex-matched control participants sat in front of a computer screen and performed four different tests to evaluate their static and dynamic acuity (Schneiders, Sullivan, Rathbone, Thayer, Wallis & Wilson, 2010). The results showed differences in performance for all four tests and although this was only a preliminary investigation into the visual acuity of motorsport athletes it, "demonstrates that they may have superior visual performance when compared to controls" (Schneiders et al., 2010, pg. 48). The ability to demonstrate strong static and dynamic visual acuity skills is essential for motorsport athletes and other extreme athletes when visual acuity is "integral to performance and injury reduction" (Schneiders et al., 2010, pg. 48). The combined results from these and other related or similar visual and peripheral perception studies,

demonstrate that over time athletes developed a better static and dynamic visual acuity, and a shorter response time to visual peripheral stimuli than non-athletes.

Interestingly, some studies conducted on visual perception and attention indicate the exact opposite and show that experts in team sports showed no better visual attention performance than of individual sport athletes or non-athletes. In one such study, Memmert, Simons and Grimme (2009) assessed differences in visual attention, between 3 groups (40 expert athletes in team handball, 40 athletes in non-sport teams such as track, and 40 non-athletes) by instructing participants to complete a functional field of view (FFOV) task, a multiple-object tracking (MOT) task, and an intentional blindness (IB) task. The assumption that expert athletes, or athletes on teams possess an enhanced orienting of visual attention compared to novice or non-athletes was incorrect, as the results of the study showed that “experts in a team sport showed no better performance on basic attention tasks than did athletes from non-teams sports or novice athletes” (Memmert et al., 2009, pg. 150). The results indicate that all humans possess similar visual attention abilities, which implies that anybody could successfully utilize and respond to visual stimuli during activity, although athletes are proven to have a quicker reaction time.

### **2.3.2 Visual Perception of Downhill Winter Athletes**

The sense of sight and visual perception are essential to the performance and success of any athlete but are especially important to downhill winter athletes participating in high speed sports, where a split-second decision could be the difference between success and failure which could result in injury. For some athletes, having a faster reaction times to specific visual stimuli may give them a competitive advantage in competition and similarly having good peripheral

awareness may also improve their chances of a successful training run or competition. In a study by Schläppi, Urfer and Kredel (2016) on visual perception, 22 members of the Swiss national alpine ski team were asked questions focusing on the athlete's gaze behavior when skiing, factors affecting visual perception during races, and strategies used to prevent or to cope with perceptual difficulties. The results indicated that factors affecting the athlete's visual perception during races included time pressure, vibrations, head stability, upper-body stability, compensation strategies and visibility conditions, and that some strategies used to cope with perceptual issues included race preparation, gaze behavior and skiing technique (Schläppi et al., 2016, pg. 203). The athletes surveyed in the study acknowledge that, "expertise in alpine skiing is determined by a strong mutual interdependency of perception and action" (Schläppi et al., 2016, pg. 203). This can relate back to why athletes may have better dynamic visual acuity, and a shorter response time to visual peripheral stimuli than non-athletes (Zwierko, 2008, pg. 60).

The visual perception of downhill skiers and snowboarders is forced to operate in extreme conditions, with rapidly changing environments and distances between the athlete and external objects. In a study by Aleshin et al. in 2011, a ski simulation training system was utilized to evaluate how 3D visual factors (snow, fog and rain) have an impact on the results of professional skier's virtual alpine ski race training. The results of the study show that when the intensity of the snow, fog or rain increased in the ski-simulation, the performance of the alpine skier participant decreased and they took longer to complete the course (Aleshin et al., 2011, pg. 2-3). In a study on motor imagery by Louis, Collet, Champely and Guillot (2012) athlete groups of 21 skiers (12 national level skiers and 9 recreational skiers) and 16 equestrian riders (8 elite regional licensed riders and 8 novice riders) utilized motor imagery (MI) to predict their speed and actual

performance time after a course inspection, before the start of a race, and after the actual race. The results of the study indicated that, “motor imagery and physical times were similar in expert skiers during each imagery session, while novice skiers and novice and expert riders underestimated the actual course duration (Louis et al., 2012, pg. 86). Therefore, the results show that, “the temporal accuracy of an imagery task prediction depends on the performer’s expertise level and characteristics of the motor skill” (Louis et al., 2012, pg. 86). This demonstrates how expert athletes have better mental imagery abilities which they can utilize to help better prepare themselves for competitions, by visualizing their run to reduce potential error and injury.

## **2.4 Literature Review Summary**

As presented, a literature review was conducted to survey current and existing wearable devices used to enhance user performance and assist in training, including AR headset displays for military pilots, medical professionals and different types of athletes. Additional research included a review of how simulation training systems for athletes are designed, as well as basic principles of visual perception that apply to digital screen design and AR headsets. Principles of spatial orientation, military aircraft pilot head-mounted-displays and the iconography used to transmit information to the pilots were reviewed to determine if the principles were transferrable to downhill winter athletes who may also benefit from utilizing AR headsets. Methods of human-centred-design (HCD) identified by Maguire (2002) which are used by industrial design professionals, were analyzed to determine how these methodologies could be used and adjusted for application in my own research. Identified through the literature was an opportunity to utilize an AR headset to improve downhill winter athlete visual perception and spatial awareness, by assessing visual variables and the spatial awareness skills of end-user participants who have

experience in downhill winter sports. Figure 2-3 below, illustrates the various topics researched in the literature review and the progression of the research through different and related topics toward a final thesis direction and study question. Overlapping or touching bubbles and arrows indicate relationships between the literature review topics which were grouped into four different categories: technology, end-users, perception and design.

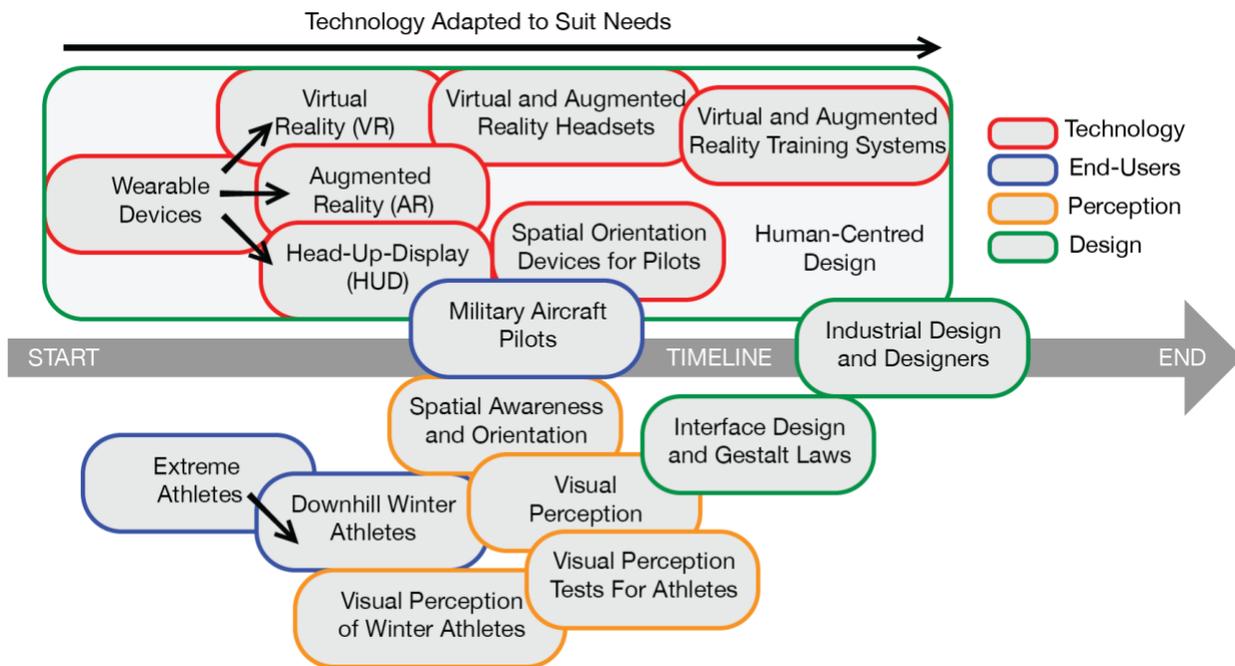


Figure 2-3. Literature Review Map

### **3.0 METHODS:**

Some of the research methods used during this thesis study were adopted from Vijay Kumar's book 101 Design methods: A structured approach for driving innovation in your organization (2013). The data collection methods have been divided into four separate phases, which are the following; a) the introduction surveys (consent form, pre-test survey and skill level assessment), b) the experience simulation and interface testing, c) the post-test survey and d) the user response analysis. Both qualitative and quantitative data were collected from the participants and a mix of both open and closed-ended questions and multiple choice questions used in the surveys.

#### **3.1 Human-Centred Approach**

This thesis study takes a human-centred and collaborative approach to determine the design requirements and barriers for developing an optimal augmented reality headset for downhill winter athletes, which will help to improve their overall visual perception and awareness.

When developing technological products, “human-centred design (HCD) is concerned with incorporating the user's perspective into the software development process in order to achieve a usable system” (Maguire, 2001, pg. 588). During this study, all participants were subjected to the same individual augmented reality headset testing procedure, which guided them through the same interface scenarios in the same simulated ski hill environment. Each participant individually evaluated a specially developed icon displaying different colours, different locations in the field-of-view, different alert methods, and a slope angle indicator to determine which variables provide the best visual experience. All participants have a common shared experience of viewing and interacting with the augmented reality headset, while standing on the articulating test platform and immersed in the simulation. After the individual headset testing sessions,

participants used a survey sheet to indicate which of the icon variables allowed for the best visual perception of the information and were best suited for a downhill winter sport application. The participants had a wide range of skill levels, from beginner riders who have only been skiing or snowboarding once, to expert and competitive level riders who had many years of experience. Each participant used their own personal experience and expertise in downhill winter sports, combined with the common shared experience from the simulation to reach a conclusion on what the final design recommendations and barriers for an augmented reality headset would be. At the end of each test session is an opportunity for each participant to provide any unstructured, verbal or written comments related to the headset, icon design, study structure, areas for improvement or potential features that could be included in the icon to improve the headset usability.

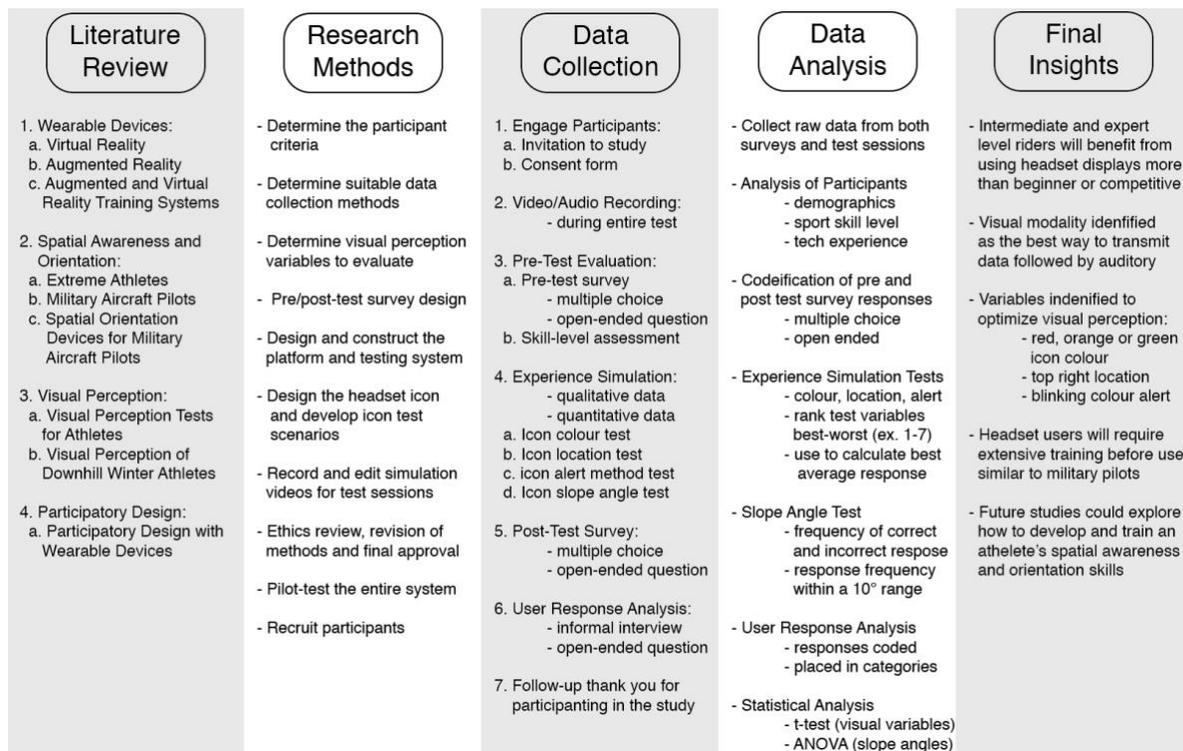


Figure 3-1. Methods Map

### **3.2 Methods Map**

The methods map (Figure 3-1) indicates the five key segments of this research study (literature review, research methods, data collection, data analysis and final insights) in sequence from left to right. Under each segment is a list of the key activities and sub activities that were conducted during that segment.

### **3.3 Participant Eligibility and Recruitment**

Recruitment for the individual participant experience simulation testing included invitation by email, printed posters at Carleton University (See Appendix A for recruitment poster), electronic posters online, and recruitment posting in various social media groups including the Carleton Ski and Snowboard Club on Facebook™ which has over 3,000 active members. Eligible participants had no prior relationship as a coach or client to the primary researcher or each other. Participants responded to the recruitment postings and were selected based on the following criteria:

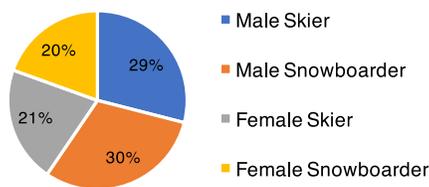
- Have participated in either downhill skiing or snowboarding at a beginner to expert skill level (participants with no experience will not be accepted for this study)
- Able bodied, good vision, no injuries or disabilities that could negatively affect balance
- All participants must be within the required age range of 18 – 55 years

In order to ensure that the participant sample size was reflective of the current Canadian skiing and snowboarding population, in terms of both gender, age and other demographic variables, statistics gathered by the Canadian Ski Council between the dates of 2014-2015 were first analyzed.

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 (Figure 3-2). A specific number of male and female, ski and snowboarding participants were selected to ensure that the sample size and results of my individual participant testing sessions were reflective of the Canadian Ski Council ratios. My thesis study had a total of 34 participants, composed 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 (Figure 3-3).

Canadian Ski Council 2014-2015 Downhill Winter Sport and Gender Statistics



Participant Gender and Downhill Winter Sport

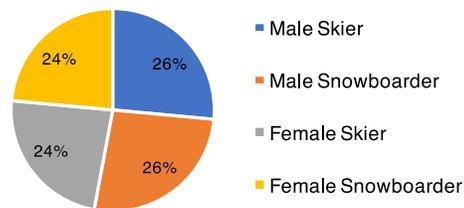


Figure 3-2. Canadian Ski Council 2014-2015 Stats      Figure 3-3. Participant Gender and Winter Sport

### 3.4 Research Procedure

The approach to conduct the research with the eligible participants is as follows (See Figure 3-4 for a visual representation of the individual participant testing steps)

- Participants that saw online or on-campus posters and contacted the primary researcher were assessed to see if they met the testing criteria. Participants that met the criteria were sent an invitation via email to participate in the experience simulation testing and scheduled a date for the 30-minute test session, which took place at Carleton University.
- Upon arrival at the test-room, participants were given a consent form (Appendix B) to read and complete, giving consent to be video recorded during the study.
- The pre-test survey was completed (Appendix C).
- The skill-level-assessment survey was completed (Appendix D).

- The primary researcher gave each participant a tutorial on how to use the headset and view the icon during the test, using a visual diagram of the icon (Appendix F).
- The primary researcher helped the participants put on and adjust the wearable equipment which included the headset, wireless headphones and the safety harness belt.
- The participant experienced the 1<sup>st</sup> simulation (icon colour) and recorded the results.
- The participant experienced the 2<sup>nd</sup> simulation (icon location) and recorded the results.
- The participant experienced the 3<sup>rd</sup> simulation (icon alert) and recorded the results.
- The participant experienced the first half of the 4<sup>th</sup> simulation (slope angle determination with no icon assistance) and the primary researcher recorded the results.
- The participant experienced second half of the 4<sup>th</sup> simulation (slope angle determination with icon assistance) and the primary researcher recorded the results.
- The primary researcher reset the system, helped each participant remove the wearable testing equipment and sanitized the equipment to prepare for the next participant.
- The post-test survey was completed (Appendix E).
- At the end of the post-test survey was an open-ended question which allowed each participant to write any additional comments or feedback, which transitioned into a brief 1-on-1 interview between the primary researcher and participant, which was recorded.
- Each participant was thanked for their participation in the study, informed that they may be contacted via email for further clarification of their responses, and offered food or drink as a form of compensation for their participation.

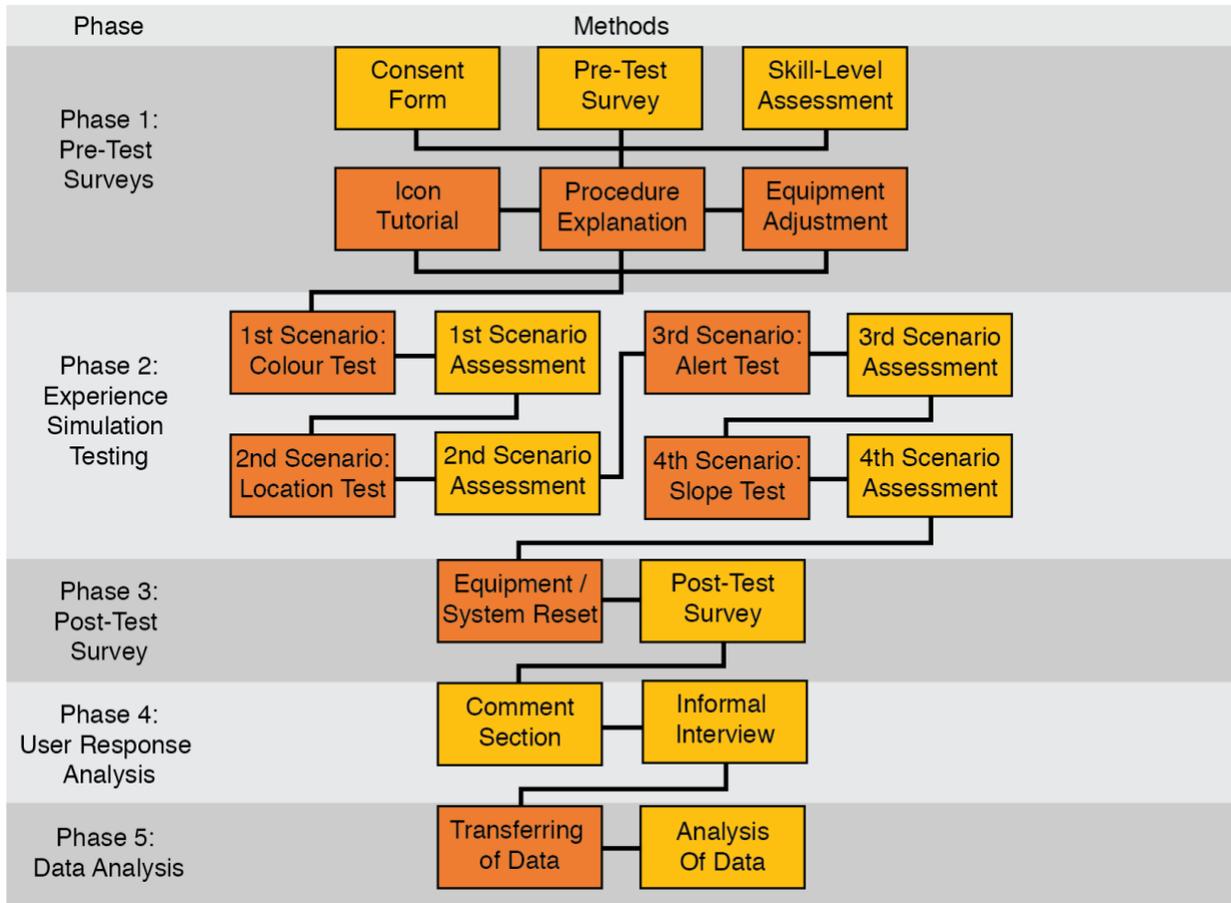


Figure 3-4. Data Collection Phase and Methods Map

### 3.5 Pre-Test Survey Design

The first, introduction data collection phase is composed of three documents; a) the consent form (Appendix B), b) the pre-test survey (Appendix C) to gather demographic data and past-experience with wearable devices, c) and the skill level assessment survey (Appendix D) to determine the participant’s current skill level for either downhill skiing or snowboarding. The pre-test survey used both multiple-choice questions and open-ended questions which gave each participant an opportunity to write their own unique response. Through this survey method the primary researcher received individual opinions to several open-ended questions as detailed qualitative data which allowed for triangulation with a different method (quantitative responses

to the experience simulation testing) related to the same primary or secondary research question (Creswell, 2014, p. 201, 231). The qualitative response data was later compared to the quantitative statistical data through triangulation to reach a conclusion. The survey began by gathering important demographic information, such as the participants age, height, and gender. Next the survey gathered information using multiple-choice questions, related to their downhill winter sport of choice, including their preferred riding style, how many lessons they have taken, how many competitions they have competed in and if they have ever been a licensed ski or snowboard instructor. The second half of the pre-test survey assessed each participant's past-experience with wearable technology, virtual reality, and augmented reality devices and asked each participant to select how frequently they use these forms of technology using multiple-choice responses and then indicate the specific devices they used by listing them in an open-ended question form. The pre-test survey ended with one final open-ended question which instructed each participant to write their own definition of augmented reality, which helped to determine if the participant was familiar with the subject or if AR technology was new to them.

### **3.6 Participant Skill Level Assessment Design**

The participant skill assessment (Appendix D) evaluated a participant's skiing or snowboarding skill level, to first categorize participants as beginner, intermediate, expert or competitive, and then give them a secondary skill level number ranging from 1-9 (1 being beginner and 9 being competitive). The skill levels were determined based on the various types of terrain and difficulty of slopes the participant can navigate (eg. green circle, blue square, black diamond), their ability to ride difficult features in the terrain park, or off-piste (forest) trails, and if they compete in races, or other competitions. Participants read short descriptions of each level and

then they selected the skill level number and category that best represented their current skiing or snowboarding capabilities. The skill levels used in this study were adapted from ski and snowboard ability levels created and posted online by credible ski mountain organizations such as Steamboat Mountain in Colorado (Ability Levels, n.d.) and Grouse Mountain in Canada.

### **3.7 Experience Simulation Testing Design**

During the second data collection phase, the experience simulation and icon testing, participants were placed within a simulated winter ski hill environment module, developed to assess how each participant would perceive and react to different visual stimuli in a winter sport context. The experience simulation testing method allows researchers to explore parts of the experience that matter most to the user in a safe and controlled environment by observing the, “participants’ interactions with elements of the environment and conducting follow-up interviews with them to understand both details and overall user experience” (Kumar, 2013, pg. 297). During the experience simulation participants wore both wireless headphones and a Moverio BT-200™ smart glasses headset (Figure 3-2), and 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.



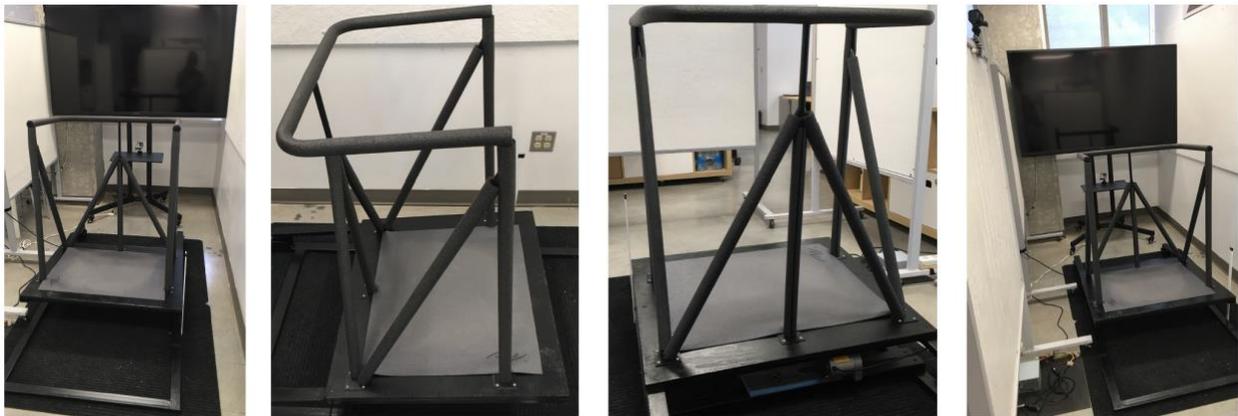
*Figure 3-5. The Moverio BT-200 Smart Glasses Worn by Participants (Google Images)*

### 3.7.1 Slope Changing Platform Design

During the simulations, 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  $5^{\circ}$  (a beginner level slope, green circle) and for the slope angle test changed to  $14^{\circ}$  (blue square) for the 2<sup>nd</sup> interval,  $20^{\circ}$  (black diamond) for the 3<sup>rd</sup> interval and back down to  $9^{\circ}$  (green circle) for the final 4<sup>th</sup> interval. The angle intervals were selected based on the information by Ronald Kip, in the book *Alpine Skiing* (2011) which revealed that in North America; green circle slope gradient: 6-25% ( $0-11^{\circ}$ ), blue square slope gradient: 25-40% ( $12-18^{\circ}$ ), black diamond slope gradient: 40% ( $19^{\circ}$  and up).

When developing the design of the test apparatus, research on simulation training systems, led to the design of a remote controlled, slope changing test platform (See Figure 3-6) that simulated the forces of downhill skiing or snowboarding. The platform was used in conjunction with the simulation video and wireless headphones that provided howling wind sounds, to create a somewhat realistic sensorial experience for the participants by stimulating their visual, auditory, spatial and tactile senses. Due to ethical concerns, it was not realistic to perform these tests with humans on a real ski hill so designing a specialized simulation system to deliver a realistic downhill winter sport experience to each participant was necessary to conduct this research and collect relevant data. Analysis and assessment of the pivot point, weight distribution, stability and safety railing systems helped to inform the design. 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

during simulations. 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. The wireless headphones worn by participants played mountain wind sounds on loop to add an auditory layer to the simulation which also helped to deafen the sound of the electric car jack motor and platform moving. During testing, white walls were positioned around the slope changing platform to enclose the participant and block out any external distractions. To increase safety, participants wore a belt around their waist which was fastened securely to the platform's padded safety railing with a cord and metal carabiner to prevent tripping or falling during testing.



*Figure 3-6. Pictures of the Slope Changing Platform and Equipment in the Test Room*

Prior to the fabrication of the slope changing platform and test-system orthographic drawings of the proposed simulation testing set-up were developed to plan the construction. The key features of the slope changing platform and headset simulation system are as follows (Figure 3-7):

- Moverio BT-200: an augmented reality headset used to display the icon during the testing
- Wireless Headphones: played ambient mountain wind sounds during the entire simulation
- 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°

- 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
- Safety Harness: a belt worn by participants, clipped to the safety railing to prevent falling
- Safety Enclosure: padded metal railing that participants held onto during the simulation
- Rubber Floor Pad: gave the participants extra foot grip when the platform angle was steep
- GoPro™ Cameras: two cameras were used to record front and side views during testing

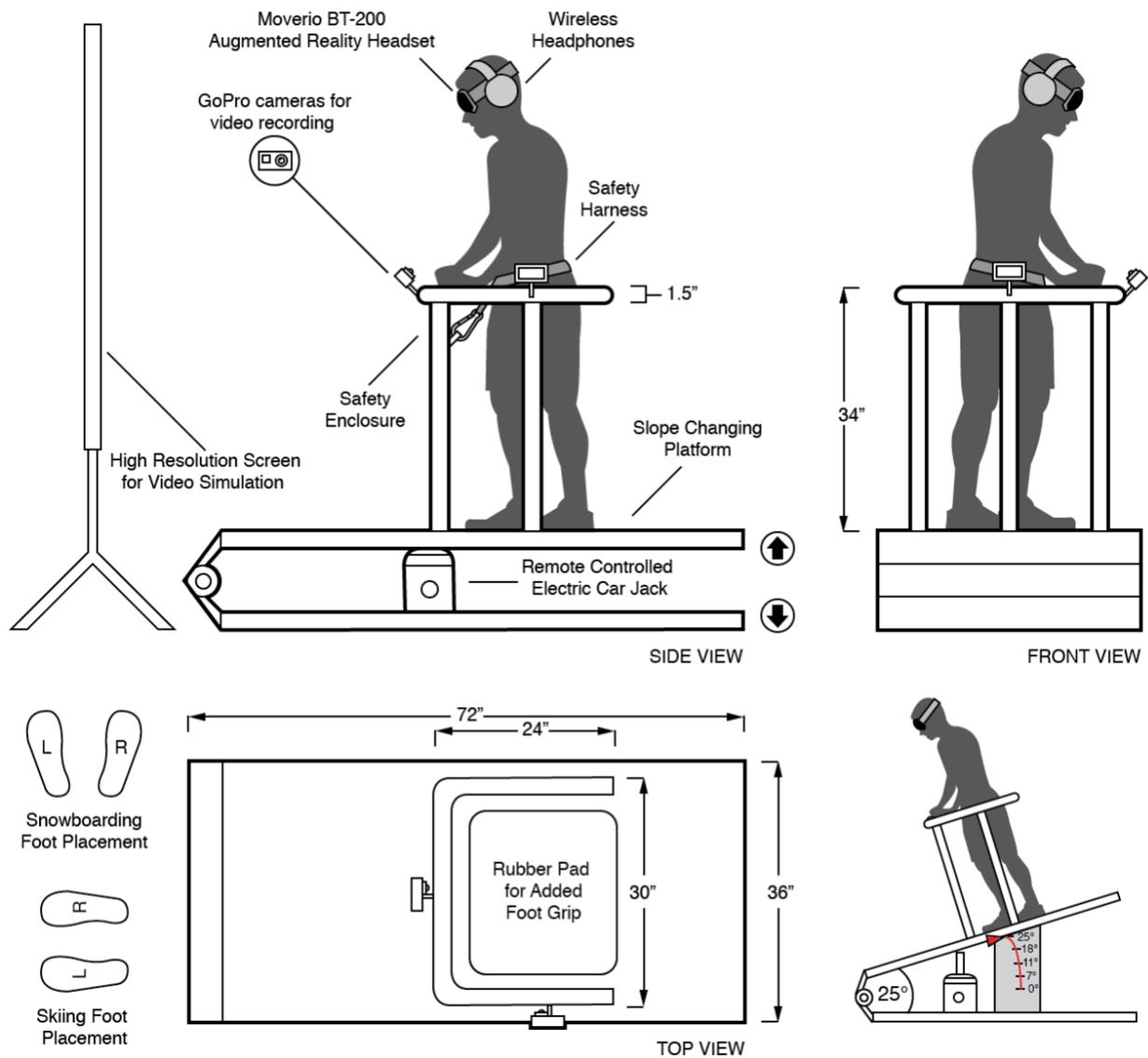


Figure 3-7. Isometric Plans of the Slope Changing Platform Design and Associated Equipment

### 3.7.2 Augmented Reality Icon Design

The visual icon (Figure 3-8) displayed in the headset was used to assess different variables of visual perception during four test scenarios: a) icon colour, b) icon location in the field-of-view, c) icon alert method and d) icon slope angle indication method. Before the test session began the primary researcher gave each participant a brief tutorial on what to do during each test scenario, showed them an example of the icon used during the test and explained the different variables and features within the icon. 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. Icons and symbols currently used in AR displays by military aircraft pilots including icons and principles described by Eric Geiselman (2002) were studied and used as guidelines for developing the icon for this research study. During the icon colour scenario, participants stood on the platform and viewed the icon displayed in the headset which changed to a different colour every 7 seconds, based off the visual spectrum of colours or ROYGBIV (red, orange, yellow, green, blue, indigo, violet). Immediately after the scenario is completed the participant was 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). The other two scenarios followed a similar structure, allowing participants to input their feedback immediately after viewing the different icons.

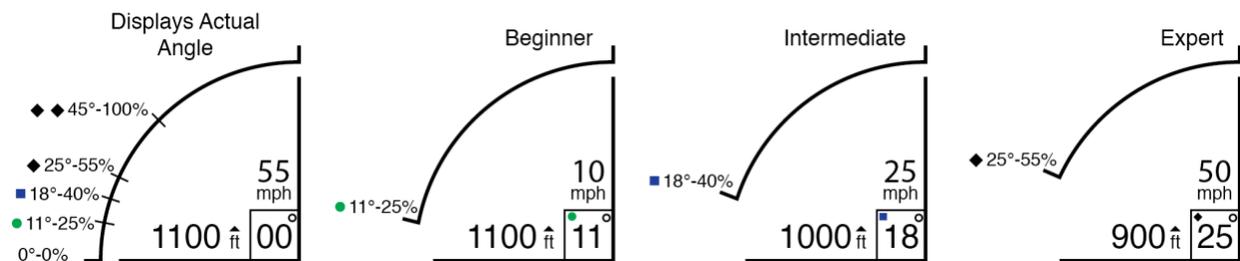
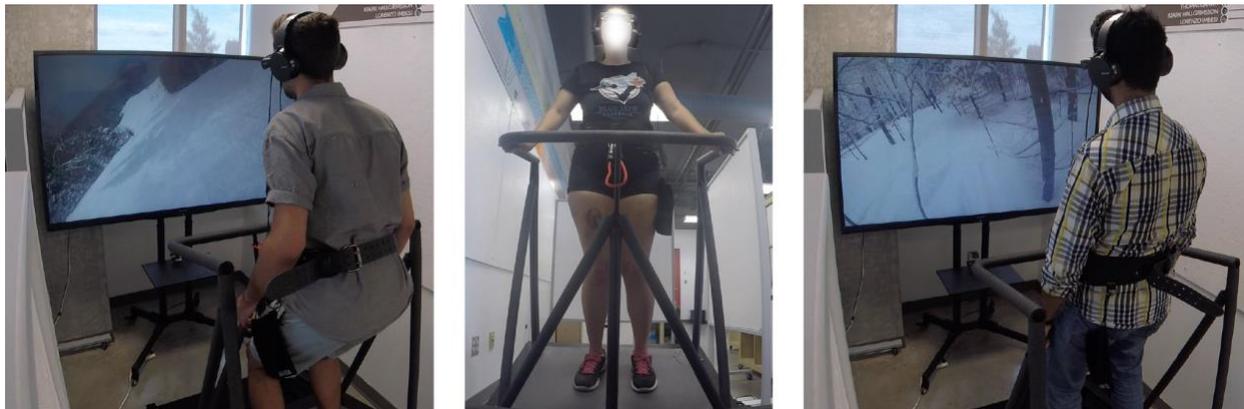


Figure 3-8. Icon Designed to be Displayed by the Moverio Headset During Testing

During the fourth and final test 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 (Figure 3-5). 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.



*Figure 3-9: Participants Standing on the Platform During Experience Simulation Testing*

### **3.8 Post-Test Survey Design**

The post-test survey (Appendix E) administered gained insights from participants on effect that the different visual perception variables (color, location, alert method) had on the visual perception of the icon during the simulations using a ranking system (ex. 1=best, 7=worst). The survey was also used to determine if having access to the icon improved the participant's

performance in determining the correct angle of the slope changing platform. Much like the pre-test survey, the post-test survey consisted of both multiple-choice answers and open-ended questions. Multiple-choice responses were used to assess if the icon improved the participant's accuracy and speed when determining the platform slope angle, and to evaluate the usability and comfortability of the headset. The ranking system used to assess the effect of different visual perception variables (color, location, alert method) was also used to evaluate which of the five senses would be best suited for transmitting information to downhill winter athletes.

### **3.9 Qualitative User Response Analysis**

At the end of the post-test survey was a section for the participants to express any comments, issues or ideas to help improve the design and usability of the visual icon, headset and simulation system. This section was an informal 1-on-1 discussion with the participant and the primary researcher which was video recorded with some written transcription, which was later analyzed to determine valuable insights to this research study. This method, known as User Response Analysis, is defined by Vijay Kumar in the book 101 Design Methods as, “a method that uses data visualization techniques, such as color and size, to analyze large quantities of qualitative data gathered from user surveys, questionnaires, interviews, and other ethnographic research methods” by arranging and grouping responses to uncover patterns and insights. The participant's responses were organized in an Excel™ spreadsheet, keywords were identified and the participant's post-test comments were grouped based on these keywords.

### 3.10 Quantitative Statistical Analysis

Qualitative results from the four icon test scenarios within the experience simulation testing, were analyzed based on average rank and frequency of ranks for each variable, and a T-test and ANOVA test was performed on each corresponding data set to determine the significance of the result. A t-test is defined by the Merriam-Webster dictionary as, “a statistical test involving confidence limits for the random variable  $t$  of a  $t$  distribution and used especially in testing hypotheses about means of normal distributions when the standard deviations are unknown”. T-tests are used to compare two data sets to determine if the results are significantly different and were used in this study to compare the slope with-icon results and no-icon test results. An ANOVA test is defined by the Merriam-Webster dictionary as, “analysis of variation in an experimental outcome and especially of a statistical variance in order to determine the contributions of given factors or variables to the variance”. An ANOVA test was used to compare the mean values of the different variables within the icon colour, location and alert data sets to determine their statistical significance. The standard deviation was calculated for each variable to determine if there was any overlapping of the standard deviation values which would indicate less statistical significance. The Merriam-Webster dictionary defined standard deviation as, “a parameter that indicates the way in which a probability function or a probability density function is centered around its mean and that is equal to the square root of the moment in which the deviation from the mean is squared.” The quantitative data was then compared to qualitative responses to find any similarities.

## **4.0 DATA COLLECTION AND RESULTS**

During the data collection segment of the research study, both quantitative data and written or verbal qualitative data was recorded and compiled into a spreadsheet for analysis. For the pre-test, post-test and skill level assessment surveys participants read multiple choice questions and responded by selecting an option provided or by writing a response to an open-ended question. During the experience simulation testing method, participants stood on slope changing platform and reacted to visual stimuli to assess different variables of visual perception and their own spatial orientation and awareness abilities. At the end of the post-test survey, a section for final comments allowed the participant to express any issues, concerns or ideas to help improve the visual system which ended with an informal 1-on-1 discussion with the researcher.

### **4.1 Data Collection Period**

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, but varied slightly depending on the length of some participant responses. 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. Upon completing the experience simulation testing each participant was asked to complete a post-test survey and finish the study with a 1-on-1 interview with the researcher, which allowed each participant to express any final comments. The experience simulation testing was conducted at Carleton University in the Masters of Design (MDes) Studio, a quiet room with no external noise or visual distractions present.

#### **4.2 Participant Classification – Pre-Test Survey Results:**

The pre-test survey gathered standard and basic demographic data such as the participants age, height and gender. More specific information related to the participant's preferred downhill winter sport (skiing or snowboarding) activity was collected, probing with questions such as:

- What type of downhill skiing or snowboarding do you prefer (leisure, terrain park, etc.)
- Have you ever received ski or snowboarding lessons and how many?
- Have you ever taught lessons as a licensed instructor and how many?
- Have you ever competed in races or trick competitions and how many?

The pre-test survey also questioned participants on their past-experience with wearable technologies, augmented and virtual reality devices during activity, asking them:

- How often do you use wearable tech devices during an activity and which devices?
- How often do you use virtual reality headsets during an activity and which devices?
- How often do you use augmented reality devices during an activity and which devices?

Participants were also asked to indicate “yes” or “no” if they were aware of what augmented reality is and then provide a short definition in their own words, in order to assess the response and determine its accuracy.

During this research study a total of 34 participants were tested; 9 male skiers, 8 female skiers, 9 male snowboarders and 8 female snowboarders, for a final ratio of 52% male and 48% female for each sport category. Based on individual skill level in their downhill winter sport of choice (see Skill Level Assessment Survey in Appendix C) participants were placed into a group-level and skill-level as either Beginner (skill-level 1, 2, 3), Intermediate (skill-level 4, 5, 6), Expert (skill-level 7, 8) or Competitive (skill-level 9) (Figure 4-1). The data collected, indicated that out

of a total of 34 participants there were 10 participants (29%) at the beginner skill level, 7 participants (21%) at the intermediate skill level, 16 participants (47%) at the expert skill level and 1 participant (3%) at the competitive skill level (Figure 4-2).



Figure 4-1. Participant Skill Level



Figure 4-2. Participant Skill Level Group

Participants were also categorized based on their primary method of riding for their downhill preferred downhill winter sport, which indicated that 26 participants (76%) preferred leisure riding as their primary method, 4 participants (12%) preferred the terrain park, 3 participants (9%) preferred back-country or off-piste riding, and 1 participant (3%) preferred racing while riding (Figure 4-3). This revealed that over 75% of participants selected leisurely riding as their preferred method of downhill riding, indicating that they do not participate in more dangerous and expert-level riding in terrain parks, in different types of races, or on back-country trails.

Participants were asked about their past experiences using wearable devices during a physical activity, and 16 participants (47%) indicated they never used wearable devices during an activity, 8 participants (23%) rarely used wearable devices during an activity, 5 participants (15%) sometimes used wearable devices during an activity and 5 participants (15%) indicated they used wearable devices during an activity very often (Figure 4-4). Wearable devices that participants said they used during physical activities include models of the Fitbit™, iWatch™ and GoPro™,

and smartphone apps like the iPhone™ health app and the Strava™ cycling app. This data shows that slightly over half the participants (53%) have some sort of past-experience using a wearable device during a physical activity, which was surprising given the wide use of smartphones.

Participant Downhill Winter Sport Riding Style

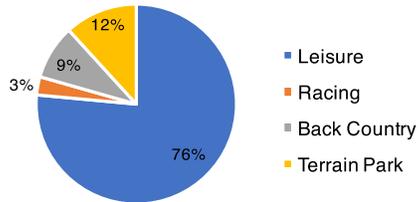


Figure 4-3. Participant Riding Style

How Often Participants Use Wearable Tech Devices During Athletic Activities

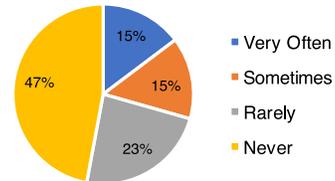


Figure 4-4. How Often Participants Use Wearable Tech

When asked about previous experiences with virtual reality (VR) devices 16 participants (47%) indicated they have never used a VR device before, 16 participants (47%) rarely used VR devices, 2 participants (6%) sometimes used VR devices and 0 participants (0%) used VR devices very often (Figure 4-5). The 18 participants (53%) who indicated having some past-experience with VR devices, indicated that they used devices such as the Oculus Rift™, HTC Vive™, Google Cardboard™ and Samsung Gear™.

Participants were evaluated on their overall knowledge and past-experience with augmented reality (AR) devices and headsets. 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 often use of AR devices (Figure 4-6). This data suggests that although the participants may be aware of what AR is and understand its definition, only a small number of participants have used AR devices during their daily activities, or during a physical activity.

How Often Participants Use Virtual Reality Devices During Activities

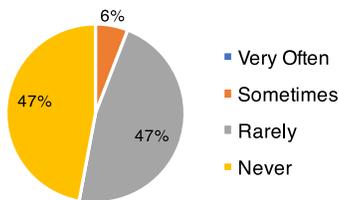


Figure 4-5. How Often Participants Use VR

How Often Participants Use Augmented Reality Devices During Activities

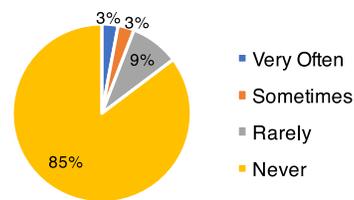


Figure 4-6. How Often Participants Use AR

### 4.3 First Scenario – Icon Colour

During the 1<sup>st</sup> test scenario participants stood on the slope changing platform, in front of a high-resolution screen, wearing headphones and used the headset to evaluate the different colours of the test icon and rank them based on which colour was the most visible and easy to read. The seven icon colours used during this research study were; red, orange, yellow, green, blue, indigo and violet (Figure 4-7). These specific colours were selected because they belong to the visible spectrum of colours that can be seen by humans. Each coloured icon was presented for approximately 7 seconds before switching to the next coloured icon, giving each participant a period-of-time to move their eyes and head to evaluate the visibility of each icon. Immediately following the 1<sup>st</sup> test scenario the participants remove the headset and use the post-test survey sheet to rank the seven icons from most visible and easy to read (rank 1) to least visible and difficult to read (rank 7). After the 34 participants completed the icon colour scenario, the responses were analyzed and averaged to determine which colour icon was perceived as the most

visible and easy to read. An ANOVA test was conducted to determine the statistical significance of the data sets, which was found to be significant with a p-value of 2.17751E-21, less than 0.05.

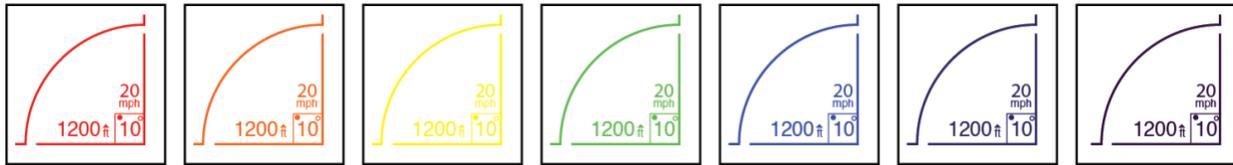


Figure 4-7. Icon Colours (from left) Red, Orange, Yellow, Green, Blue, Indigo, Violet

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 (Nicholl, 2014). A secondary hypothesis was that the red icon would also be ranked high due to its stark contrast to the outdoor winter environment and its use in current consumer AR headset displays. However, the results indicated that the orange coloured icon was ranked with the best average rank or mean (mean =  $2.91 \pm 1.44$ ), followed closely by the red icon in second (mean =  $2.94 \pm 1.82$ ) and the green icon in third (mean =  $2.97 \pm 1.51$ ). The yellow icon was ranked fourth (mean =  $3.5 \pm 2.08$ ), blue in fifth (mean =  $4.0 \pm 1.60$ ), indigo in sixth (mean =  $5.56 \pm 1.26$ ) and violet (mean =  $6.12 \pm 1.37$ ) was ranked as the worst overall in seventh place (Table 4-1). The participant ranked responses to each of the different variables during the icon colour, location and alert method tests were considered subjective data because the results were based off each participant's own opinion and preference, for example which colour they perceived as the most visible and easy to read in the display. This data suggests that orange, red and green coloured icons were preferred as the most visible and easy to read in this downhill winter sport simulation as these coloured icons had very similar mean rankings of around 2.9. The cool tone, coloured icons (blue, indigo, and violet) were ranked by the participants as the worst overall in 5<sup>th</sup>, 6<sup>th</sup> and 7<sup>th</sup> place respectively, which

could be a result of users being exposed to many outdoor cool-blue tones during a winter activity, which would interfere with the end-user’s ability to view the icon. Although participants preferred the orange, red and green icons, further analysis of the data indicated overlapping of the standard deviation of some means, indicating that some of the results may not be conclusive, and that additional testing may be required. The standard deviation of the violet icon, which had the lowest mean of  $6.12 \pm 1.37$ , did not overlap with the standard deviation of the mean for the orange or green icons. This indicated that the orange and green icons were conclusively perceived as more visible and easy to read by participants than the violet icon.

Participant Rank System	Icon Colours						
	Red	Orange	Yellow	Green	Blue	Indigo	Violet
Rank 1 (Best)	9	4	9	7	4	0	1
Rank 2	8	12	3	7	2	2	0
Rank 3	5	9	6	6	6	1	1
Rank 4	6	4	5	11	4	3	1
Rank 5	3	3	4	1	16	2	5
Rank 6	0	1	3	1	0	22	7
Rank 7 (Worst)	3	1	4	1	2	4	19
Mean (Average)	2.94	2.91	3.50	2.97	4.00	5.56	6.12

*Table 4-1. Icon Colour Test: Frequency of Participant Ranking and Average Ranking*

#### **4.4 Second Scenario – Icon Location**

In the second scenario, participants used the headset to evaluate the location of the icon in their field-of-view and determined which location was the best for displaying data while also being

non-distracting and unobtrusive to the end-user. A neutral white coloured icon was used during this test scenario that changed every 7 seconds between five pre-determined locations (Figure 4-8) in the field-of-view: a) top left, b) top right, c) bottom left, d) bottom right and e) centre of the display. In a similar way to the first scenario, each participant immediately used the post-test survey to rank the icon locations in the field-of-view from the best location, most unobtrusive and non-distracting (rank 1) to the worst viewing location (rank 5), giving each icon a number. The ranking values for each icon location were analyzed and averaged to determine which location in the field-of-view was perceived as the most unobtrusive, non-distracting and comfortable location for viewing the icon. An ANOVA test was also conducted and determined the data set was statistically significant with a p-value of 6.7689E-09, less than 0.05.

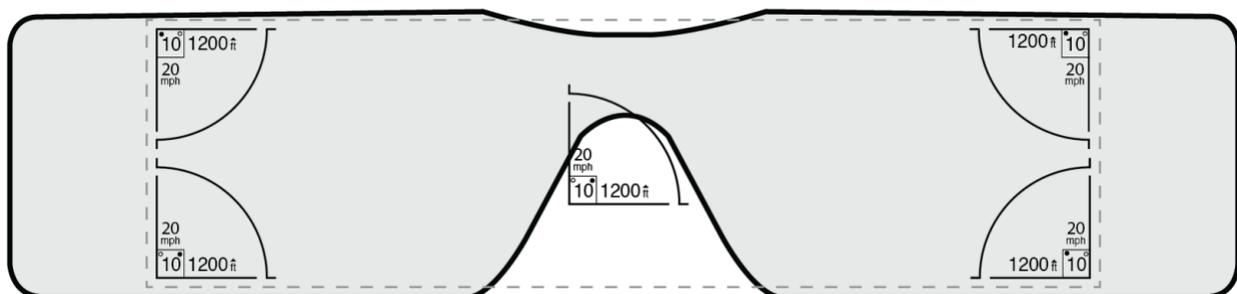


Figure 4-8. Icon Locations in the Headset Display: Top-Left, Bottom-Left, Middle, Top-Right, Bottom-Right

The hypothesis for the icon location test was that the bottom-right corner icon would be ranked as the best location within the field-of-view, because large companies such as Oakley™ and Recon Instruments™ were using that location to display digital information for athletes in their consumer AR headset products such as the Oakley Airwave™ goggles and Recon Jet™ cycling glasses. 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 (Table 4-2). Both the middle location (mean = 3.41 ±

1.56) and the bottom-left location (mean =  $3.65 \pm 1.04$ ) 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 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. Further analysis of the data set indicated some overlapping of the standard deviation of the means, indicating that although participants said they preferred certain locations, some of the results were not conclusive and additional testing may be required.

Participant Rank System	Icon Locations in the Field-of-View				
	Top Right	Top Left	Bottom Right	Bottom Left	Middle
Rank 1 (Best)	12	7	9	1	5
Rank 2	9	9	9	5	2
Rank 3	9	8	7	5	5
Rank 4	4	6	7	17	0
Rank 5 (Worst)	0	4	2	6	22
Mean (Average)	2.15	2.74	2.53	3.65	3.94

*Table 4-2. Icon Location Test: Frequency of Participant Ranking and Average Ranking*

#### 4.5 Third Scenario – Icon Alert Method

In the third scenario, participants used the AR headset to evaluate four different icon alert methods, to determine which alert method was the best suited for attracting their attention while not being overly-distracting during the simulation. The white coloured icon used during this test scenario would change every 8 seconds between four different icon alert methods (Figure 4-9):

a) colour changing icon (the icon colour changes from red to white), b) pulsing icon (a white icon expands and shrinks), c) blinking icon (a white icon appears and disappears) and d) rotating icon (a white icon rotates 360 degrees). Each participant immediately used the post-test survey to rank the icon alert methods from best and most attention grabbing (rank 1) to the worst alert method (rank 4). The participant's ranking values for each icon alert method were analyzed and averaged to determine which icon alert method was perceived by participants as most attention attracting, while also being unobtrusive and not overly distracting.

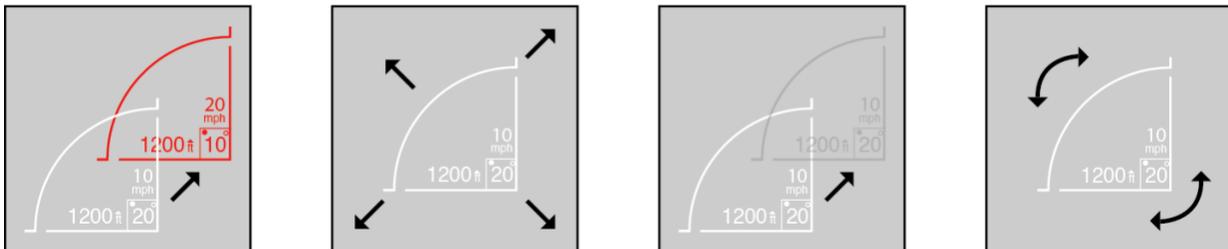


Figure 4-9. Icon Alert Methods (from left) Colour Changing, Expanding, Blinking, Rotating

The hypothesis for the icon alert method test, was that the colour changing alert method would be the most attention grabbing and ranked as the best, and the blinking icon alert ranked second, as visual perception research has shown that a quick flash of colour or icon blink in the periphery will attract the user's attention with faster reaction time than a moving icon that is not changing colour (Bartram et al, 2001, pg. 164). The subjective responses from this study showed that the colour changing icon alert method was ranked best overall (mean =  $1.71 \pm 1.06$ ), followed by the

blinking icon alert method in second (mean =  $2.35 \pm 0.88$ ), the rotating icon alert method in third (mean =  $2.53 \pm 1.11$ ) and finally the pulsing icon alert method (mean =  $3.41 \pm 0.70$ ) was ranked worst overall (Table 4-3). 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. This result is consistent with past visual perception test studies, which indicate that blinking icons will capture the end-user's attention more effectively translational or rotational motion (Bartram et al, 2001, pg. 164). However, analysis of the data indicated some overlapping of the standard deviation of the means for each alert method, indicating that although participants said they preferred certain alert methods over others, some of the results were not conclusive and additional testing may be required. An ANOVA test was also conducted to determine the statistical significance of the data which was found to be significant with a p-value of  $4.09418E-10$ , less than 0.05.

Participant Rank System	Icon Alert Methods			
	Colour Changing	Expanding	Blinking	Rotating
Rank 1 (Best)	22	0	4	8
Rank 2	3	4	19	8
Rank 3	6	12	6	10
Rank 4 (Worst)	3	18	5	8
Mean (Average)	1.71	3.41	2.35	2.53

Table 4-3. Icon Alert Test: Frequency of Participant Ranking and Average Ranking

#### **4.6 Fourth Scenario – Icon Slope Angle Indicator – No Icon Indicator**

The 4<sup>th</sup> test scenario was divided into two separate segments: the no-icon test segment, and the icon assisted test segment. Before the scenario began, participants were asked estimate the current slope angle of the slope changing platform at its resting position (5°) using only their visual and spatial awareness skills. In the first segment, participants stood on the slope changing platform, wearing the headphones and the headset which instructed them, to attempt to determine the platform's slope angle using only their visual and spatial awareness skills, at three specific intervals (14°, 20°, 9°) during the simulation video. While each participant watched the simulation video, the headset displayed text that said, “3, 2, 1, Determine Slope Angle Now” prompting the participant to say out loud what they thought the platform slope angle was at that exact moment. All four slope angle responses were recorded by the primary researcher and the test system was reset for the second segment of the 4<sup>th</sup> scenario.

The hypothesis for the 4<sup>th</sup> scenario was that participants would be unable to accurately estimate the platform slope angle using only their visual, and spatial awareness abilities. A secondary hypothesis was that with the addition of an icon in the display of the headset that indicated the platform's changing slope in-real-time, participants would be able to determine the slope angle much more quickly and accurately if they interpreted the icon correctly. The results from the first segment (no-icon) indicated that for the first angle interval of 5° (the platform resting position) participants responded with an average angle of 10.97°; for the second angle interval (14°) the average response was 39.65°; for the third angle interval (20°) an average response of 44.94°; and for the final fourth angle interval (9°) the average response was 18.75°. The data shows that without an assistive icon displayed in the AR headset for all four angle intervals, the average

participant response incorrectly estimated the platform slope angle by approximately 2 times at any specific interval. These results suggest that it is difficult for an individual to use only their visual and spatial awareness abilities to accurately determine the angle of the slope.

The data from this study showed that for the first, resting angle interval ( $5^\circ$ ) 6 participants (18%) responded with the correct angle, and 22 participants (66%) responded within the range of  $0^\circ$ - $10^\circ$  (Figure 4-10). For the second angle interval ( $14^\circ$ ) no participants responded correctly and only 6 participants (20%) answered within the range of  $11^\circ$ - $20^\circ$  (Figure 4-11). For the third angle interval ( $20^\circ$ ) 2 participants (6%) answered correctly and 4 participants (12%) answered within the range of  $16^\circ$ - $25^\circ$  (Figure 4-12). Finally, for the fourth angle interval ( $9^\circ$ ) no participants answered correctly but a total of 12 participants (36%) answered within the range of  $6^\circ$ - $15^\circ$  (Figure 4-13). When the platform was at its resting position ( $5^\circ$ ) 18% of participants responded correctly and 66% participants answered within a  $10^\circ$  range, compared to the remaining three angle intervals which has significantly less participants respond correctly or accurately within a  $10^\circ$  range. This could be an indication that the participants had more time to look around and assess the slope angle while the platform was at rest, and therefore had a more accurate response.

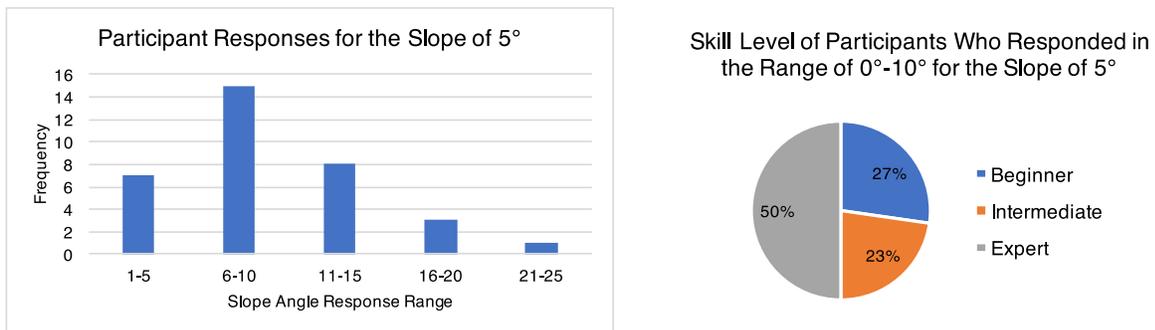
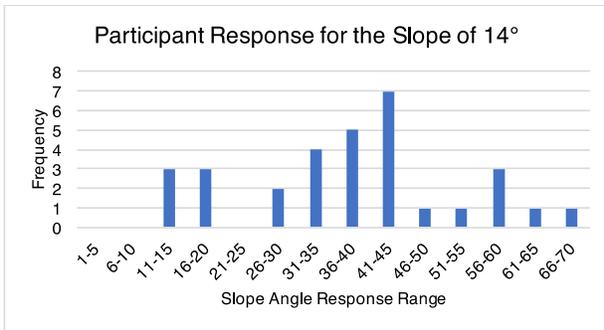


Figure 4-10.  $5^\circ$  Test Responses and Skill Level of Participants Who Responded Within  $0^\circ$ - $10^\circ$  Range



Skill Level of Participants Who Responded in the Range of 11°-20° for the Slope of 14°

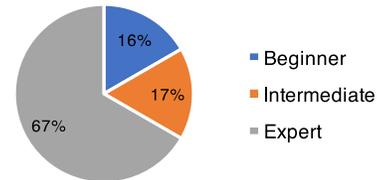
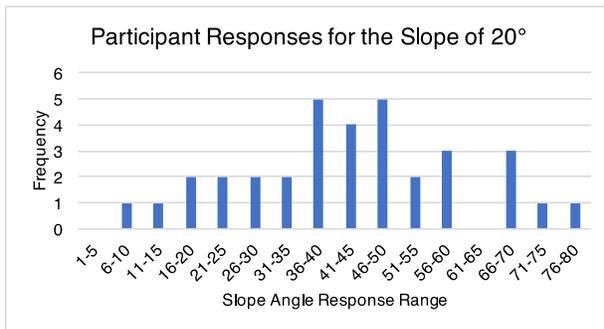


Figure 4-11. 14° Test Responses and Skill Level of Participants Who Responded Within 11°-20° Range



Skill Level of Participants Who Responded in the Range of 16°-25° for the Slope of 20°

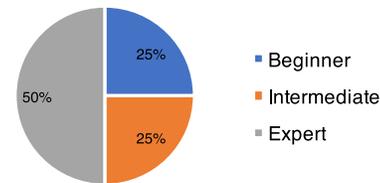
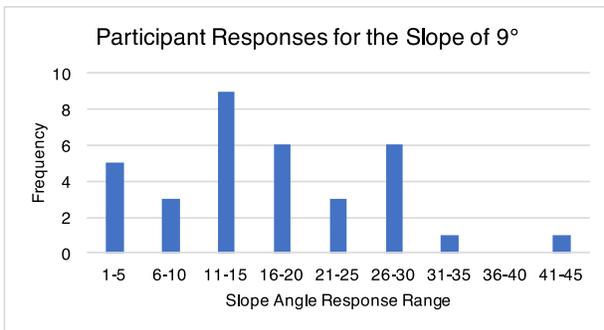


Figure 4-12. 20° Test Responses and Skill Level of Participants Who Responded Within 16°-25° Range



Skill Level of Participants Who Responded in the Range of 6°-15° for the Slope of 9°

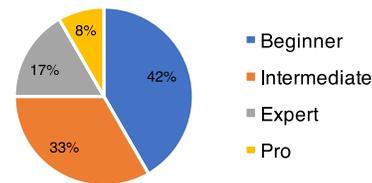


Figure 4-13. 9° Test Responses and Skill Level of Participants Who Responded Within 6°-15° Range

Further analysis of the individual participants who responded correctly, or within the specified 10° range for each angle interval tested without icon assistance revealed interesting information related to their skill and experience levels. Individual participant responses revealed that four participants did exceptionally well, which may be a result of their sport skill level and past-experience on ski hills. The top three high scoring participants were as follows:

First, was an intermediate (lvl.5) female skier, 52 years old:

- Responded correctly with the exact answer for 3<sup>rd</sup> interval (20°); and
- Answered accurately within the 10° range for all 4 intervals

Second, was an expert (lvl.8) male snowboarder, 22 years old (works in ski industry):

- Responded correctly with the exact answer for 3<sup>rd</sup> interval (20°); and
- Answered accurately within the 10° range for all 4 intervals

Third, was an expert (lvl.8) male skier, 24 years old:

- Answered accurately within the 10° range for all 4 intervals

This analysis showed that the top three participants all answered accurately within the specified 10° range for all 4 angle intervals, but only two of the top three participants also responded correctly with the exact answer for an interval (3<sup>rd</sup> interval, 20°). Two of these top three participants were expert level riders, with one rider indicating in a post-test interview that he, “currently works in the downhill ski and snowboard industry constructing free style terrain parks”. The third of the top three participants identified herself as an intermediate (lvl.5) skier, although she has been skiing for 40+ years, giving her many hours of experience on ski hills. The data showed that each of these riders were intermediate to expert level and had considerable experience snowboarding, or skiing, which appeared to improve their ability to accurately determine the slope of the platform using only their visual and spatial awareness skills. The results of the no-icon angle determination tests, suggest that spatial awareness skills and the ability to use visual and spatial skills to determine the slope angle of a hill is a skill that may be learned and improved through practice or experience. However, further research on the topic of spatial awareness skills with relation to downhill winter athletes must be conducted in order to confirm this observation.

#### **4.7 Fourth Scenario – Icon Slope Angle Indicator – With Icon Indicator**

For the second segment of the 4<sup>th</sup> scenario, participants wearing the headphones and AR headset viewed the simulation video playing on the high-resolution screen, while the slope changing platform cycled through the same sequence of angle intervals as the first segment. The only difference during the second segment was that the AR headset displayed a white icon showing the current slope angle, speed, and vertical altitude values in-real-time, for the participants to glance at and state aloud the slope angle at each specified angle interval. Similar to the first segment of the 4<sup>th</sup> scenario, after seeing the “3, 2, 1, Determine Slope Angle Now” message displayed on the AR headset, participants called out the current slope changing platform angle by reading aloud the correct angle value within the icon configuration.

The results from the second segment of the 4<sup>th</sup> scenario indicated that for the first angle interval (14°) there was an average participant response of 14.24°; for the second angle interval (20°) an average participant response of 20.44°; and for the final, third angle interval (9°) an average response of 9.15°. These results from the second test segment showed that all three of the average responses were within 0.5° or less of the actual slope changing platform angle, indicating a higher percentage of correct responses compared to the no-icon test segment. For the first angle interval (14°), a total of 30 participants (88%) responded correctly. For the same angle interval (14°) 4 participants (12%) responded incorrectly, of which 1 participant (3%) selected 13°, 2 participants (6%) selected 15°, and one participant selected 21° after accidentally reading the wrong variable within the icon displayed, thus this data point was considered an outlier data point (Figure 4-14). For the second angle interval (20°) a total of 31 participants (91%) responded correctly, and 3 participants responded incorrectly, of which 2 people (6%) selected

19° and one person selected 21° after reading the wrong variable once again (Figure 4-15).

Finally, for the third angle interval (9°) a total of 29 participants (85%) responded correctly, and 5 participants (15%) responded incorrectly with an answer of 10° (Figure 4-16).

Participant Responses for the Slope of 14°

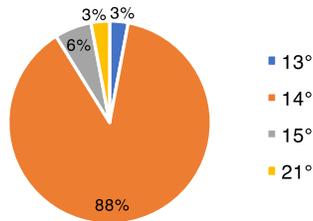


Figure 4-14. 14° With Icon Test Responses

Participant Responses for the Slope of 20°

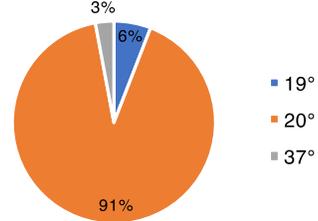


Figure 4-15. 20° With Icon Test Responses

Participant Responses for the Slope of 9°

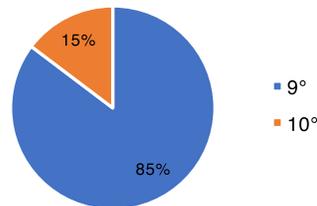


Figure 4-16. 9° With Icon Test Responses

These results suggested that the inclusion of an icon in the AR headset that displayed the current slope angle of the simulated hill in real-time, greatly improved the accuracy of participant responses. Although some experienced and high skill level participants correctly, or accurately determined the slope changing platform angle consistently without any icon assistance, with the icon assistance all the participants responded correctly or within 1° of the correct slope angle. However, one outlier participant responded incorrectly on the first and second intervals by accidentally reading the speed value (mph) instead of the slope angle value, but quickly realized her error and read the correct slope value for the third interval.

#### 4.8 Post-Test Survey and System Usability Results

The first part of the post-test survey determined the effect that 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?

The participants selected their response from a Likert-scale set of pre-determine responses (ex. very-likely, likely, unlikely, very-unlikely) and the results were analyzed and grouped based on percentage of participants to demonstrate trends and how the majority of participants responded. For most questions the participants were instructed to use a multiple choice, Likert-scale with pre-determine responses to decide if they, for example, agreed or disagreed with the statement or thought it was very-likely, likely, unlikely or very unlikely. In terms of usability of the icon in the AR headset participants to determine a slope angle more quickly than without the icon, 28 participants (82%) selected very likely on the Likert-scale, while 6 participants (18%) selected likely and no participants selected no effect, unlikely, or very unlikely. Similarly, when participants were asked if the icon helped them to determine the slope angle more accurately a

total of 33 participants (97%) selected very likely, one participant selected likely and again no participants selected no effect, unlikely or very unlikely. This data shows that all 34 of the participants in this study indicated that that it was very likely, or at least likely that an icon displayed in the AR headset assisted them in determining the correct slope angle more quickly and more accurately than without an icon.

Participants were asked to select on a Likert-scale ranging from very-easy to very-hard, the level of difficulty associated with determining the correct slope changing platform angle for both the no-icon indicator test scenario, compared to the with-icon test scenario. The data showed that with no icon assistance in the AR headset, 16 participants (44%) selected very-hard, 14 participants (41%) selected hard, 3 participants (9%) selected moderate difficulty, 2 participants (6%) selected easy and no participants selected very-easy (Figure 4-17). In contrast the data shows that with the icon displayed, 17 participants (50%) thought it was very-easy, 11 participants (32%) selected easy, 5 participants (15%) selected moderate, a single participant (3%) selected hard and nobody selected very-hard (Figure 4-18). With no icon indicator in the AR headset 85% of participants thought determining the slope angle with only their vision and spatial awareness skills was difficult and indicated the task was hard or very-hard to complete successfully. Only 15% of participants indicated that it was moderate or easy and nobody thought it was very-easy to estimate the correct slope angle. When the participants had the icon to assist them 82% indicated that it was easy or very-easy to determine the slope angle, while only 18% indicated that the task was moderate or hard and no participant selected that it was very-hard to determine the slope angle. The two data sets are almost mirror images of one another showing that the majority of the participants found determining the slope angle hard or

very-hard without an icon and easy or very-easy with an icon displayed in the AR headset. This data suggests that on average having the current slope angle displayed by an AR headset in real-time, greatly improved the participant's ability to determine the slope angle, compared to using their own visual and spatial awareness skills to determine the slope.

Participant Indicated Level of Difficulty to Determine the Slope With No Icon Assistance

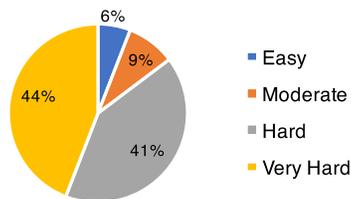


Figure 4-17. Angle Difficulty with No Icon

Participant Indicated Level of Difficulty to Determine the Slope With Icon Assistance

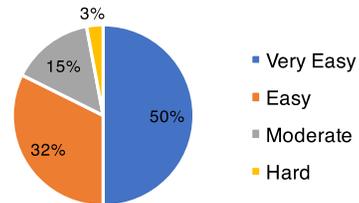


Figure 4-18. Angle Difficulty with Icon Assistance

When participants were asked if they thought that it would be useful to have access to data on spatial orientation, along with athletic data while competing or riding in a downhill winter sport activity, 11 participants (32%) indicated that this data would be very-useful, 20 participants (59%) indicated that the data would be useful, 2 participants (6%) indicated that the data would be un-useful, zero participants thought that the data would be very un-useful and one participant (3%) indicated that it would have no-effect (Figure 4-19). This data set shows that over 75% of the test participants (81%) indicated that having access to visual data during an activity would be useful on some level, indicating that the participants likely perceived the icon in the AR headset display as helpful or beneficial to their performance. When participants were asked to indicate on a Likert-scale if wearing the AR headset and viewing the icon felt natural and comfortable, 8 participants (23%) strongly-agreed, 19 participants (56%) agreed, while 7 participants (21%) disagreed and thought that the display was not comfortable and natural and zero participants strongly-disagreed (Figure 4-20). The data suggested that although the AR headset was

comfortable for 79% of the participants, 21% of the participants felt some sort of discomfort during use, which indicated an opportunity to improve the design and comfort of the physical AR headset from, and make viewing the digital AR display more natural for the end-user.

Usefulness of Headset Display During Downhill Winter Sport Activities

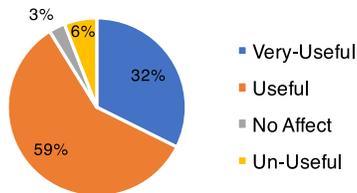


Figure 4-19. Usefulness of Headset Display

Headset Was Comfortable and Natural to Wear and Use During the Test Session

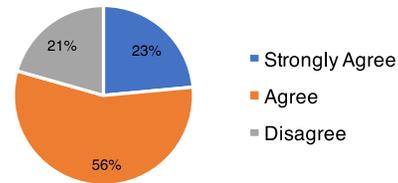


Figure 4-20. Comfortability of Headset

When participants were asked to indicate which category of downhill winter athletes would benefit the most from an assistive icon displayed in an AR headset, 6 participants (18%) selected the beginner level, 9 participants (26%) selected the intermediate level, 8 participants (24%) selected the expert level and a total of 11 participants (32%) thought that competitive level downhill winter athletes would benefit the most (Figure 4-21). The data showed that participants believed downhill winter riders with more experience and higher skill levels would benefit the most from an AR headset icon display, because they would likely have more opportunities than less experienced athletes to use the displayed data (ex. during a race, while riding forest trails, or while attempting new tricks).

Initially, it was hypothesized that an AR headset with icon display system would assist beginner level downhill winter athletes to navigate unknown ski hills, coach them through different maneuvers, and monitor their speed, location and other biometric variables during activities. However, the participant responses indicated that intermediate, expert and competitive athletes

would benefit significantly more than beginners who would likely become overwhelmed, or confused by the icon displayed in the AR headset and may have no real use for it while learning on basic hills. Although the data collected from the test participants indicated competitive level athletes could benefit most from a AR headset icon display, one competitive (lvl.9) participant mentioned that from, “having experience in ski competition, I think such information could be more distracting because we already study and train on the track prior to competing” indicating that the icon displayed in the AR headset may not be useful to experienced, competitive level riders during athletes. In the real-world, different levels of downhill winter athletes will have different uses for an AR headset display although more experienced athletes will likely have more uses for the device, however further research on this topic must be conducted to confirm this hypothesis.

The Skill Level Group Participants Think Would Benefit Most From a Headset Display

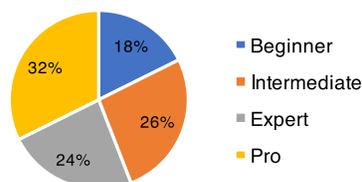


Figure 4-21. The Skill Level Group Participants Think Would Benefit Most from Headset

When participants were asked to decide if visual data and the sense of sight was best suited out of the five senses (sight, hearing, touch, smell, taste) for transmitting data to downhill winter athletes during an activity, 30 participants (88%) selected “yes”, and 4 participants (12%) selected “no”, indicating that they felt the sense of hearing and sound would transmit the data more effectively. This data showed that the test participants perceived visual data as the most effective way to transmit information to an athlete during an activity, however using sounds to

transmit data could also be beneficial. Although visually displaying the data appears most logical and effective for a downhill winter sport athlete, layering the visual data with distinct sounds for pre-determined functions (ex. a warning sound when approaching a steep slope or a notification sound when set goal is reached) could potentially improve athlete awareness and enhance their performance. However additional research on combining visual and auditory data using AR headsets needs to be explored further. Next participants were asked to rank the five senses (sight, hearing, touch, smell and taste) from best to worst in terms of which they thought would be best suited to transmit information to downhill winter athletes during an activity. The results in Table 4-4 show the frequency of each ranking for each sense and the average rank, which gave insights into which senses were perceived by the test participants as suitable for transmitting data and which senses would likely be ineffective or confusing to deliver information to the end-user via an AR headset. The results showed that sight (mean =  $1.21 \pm 0.41$ ) was ranked in first place as the most suitable sense to use in this context, followed by hearing (mean =  $2.06 \pm 0.64$ ) in second and touch (mean =  $2.88 \pm 0.73$ ) in third place. Ranked in fourth place was smell (mean =  $4.15 \pm 0.56$ ) and in last place taste (mean =  $4.71 \pm 0.53$ ) both of which seem unrealistic to use for transmitting information in a downhill winter sport context. An ANOVA test conducted on the data set generated a “p” value of  $2.57E-63$ , indicating the data as statistically significant. Tactile feedback in downhill winter sports is a relatively unexplored area however, in a recent study Spelmezan (2012), “utilized small vibrating motors integrated into a leg band which vibrated at specific intervals, indicating to the participant when to apply pressure and when to turn their shoulders while riding” instead of verbal coaching. In a similar way, audio feedback has also been used to train and guide downhill skiers or snowboarders, especially blind or vision-impaired Paralympic alpine racers, by giving them verbal directions instead of visual. As hypothesized,

the sense of sight and visual information appears to be the most effective and best suited to transmit data to downhill winter athletes during an activity. However, there may be an opportunity to layer auditory and tactile feedback with visual data to enhance the athlete’s awareness and visual perception.

Participant Rank System	Participant Senses				
	Sight	Hearing	Touch	Smell	Taste
Rank 1 (Best)	27	5	2	0	0
Rank 2	7	23	4	0	0
Rank 3	0	5	25	3	1
Rank 4	0	1	2	23	8
Rank 5 (Worst)	0	0	1	8	25
Mean (Average)	1.21	2.06	2.88	4.15	4.71

*Table 4-4. Best Sense for Transmitting Data: Frequency of Participant Ranking and Average Ranking*

#### **4.9 Qualitative User Response Analysis**

At the end of the post-test survey, participants were given a chance to write down any additional questions, comments or ideas that could help to improve the overall experience and usability of the AR headset and icon. This comment section would often lead to an informal 1-on-1 interview between the participant and primary researcher, which encouraged each participant to express valuable insights related to the visual display and ideas for improvements or additions. Some participants wrote a lot, while some participants wrote little or nothing at all but instead expressed their comments verbally to the researcher which was video recorded with audio. After

all the test simulations were completed, the written comments and the videos files were analyzed and grouped based on keywords, phrases or themes to identify trends in the responses.

From this analysis, 6 common themes were identified: 1) issues interpreting the icon, 2) the display could benefit different levels of winter athletes, 3) preference for icons located in the top level, 4) preference for icon colour, 5) icon distracting to athletes and 6) satisfaction with AR headset display. These 6 themes identified were then broken down further into sub groups:

Issues Interpreting the Icon (8 Participants Total):

- Issues caused from reading the icon values incorrectly (2 Participants)
- Issues caused when confusing the speed value with the slope value (2 Participants)
- Issues caused by not seeing the icon in the peripheral view (3 Participants)
- Issues caused by external visual and auditory distractions (1 Participant)

Display Could Benefit Different Levels of Downhill Winter Athletes (4 Participants Total):

- Display could assist beginner level athletes on new hills (1 Participant)
- Display could assist experts in competitions or doing tricks (3 Participants)

Preference for Icons Located in the Top Level (5 Participants Total):

- Preferred top level icons due to past-experience playing video games (2 Participants)
- Preferred top level icons due to issues changing focus between the icon located in the bottom of the field-of view and the ground in the simulation video (3 Participants)

#### Preference for Icon Colour (5 Participants Total):

- Preferred the bright white coloured icon over any of the coloured icons (3 Participants)
- Preferred the red and white icons over the rest of the coloured icons (2 Participants)

#### Icon Distracting to Athletes (2 Participants Total)

- A potential opportunity to explore using sound to transmit data (2 Participants)

#### Satisfaction with AR Headset Display (4 Participants Total)

- General satisfaction with how the icon functioned and was displayed (4 Participants)

The user response analysis method helped to identify issues with the display that multiple participants experienced, while also confirming some findings and results from other data collected, supporting the final conclusions. For example, the two top level locations of the icon (top-right and top-left) were ranked as first and third best locations for viewing by participants during the icon testing simulations. This was supported by the user response analysis of 1-on-1 participant interviews, which indicated that participants preferred top level icons over bottom or mid-level icons. Additionally, during the 1-on-1 interviews multiple participants indicated that their preference to top level icons was based on their own, “past-experience playing video games” or because participants had, “issues changing visual focus between the bottom icons in the display and the ground in the simulation video”. In a similar way, the user response analysis helped to give the primary insights into why each participant reacted a certain way during the testing, or why each participant has a certain preference in terms of icon colour, location or alert.

#### 4.10 Qualitative Statistical Analysis of the Data

A t-test is often used in human-computer interaction studies to compare the differences between two conditions or data sets to see if they are statistically significant from one another, and a t-test was used to compare the response data from the no-icon and icon assisted tests in the 4<sup>th</sup> scenario. The result of a t-test analysis is a single number called “P” or the probability value, and if this value is less than 0.05 that means the difference between the two data sets were statistically significant. When comparing the two no-icon and with-icon data sets, because both sets of data come from the same participants this is identified as a related or paired t-test. The researcher must also indicate how many tails the t-test has, if there is a hypothesis predicting a difference between the two data sets then the t-test is a 1-tail test, however if the researcher is unsure they can indicate that the t-test is a 2-tail test. The results of the t-test on the three data sets revealed that: (no-icon 14° vs. with-icon 14°)  $P = 2.91E-08$ , (no-icon 20° vs. with-icon 20°)  $P = 7.15E-10$  and (no-icon 9° vs. with-icon 9°)  $P = 1.65E-06$ . This analysis showed that the “p” value for these data sets were much lower than 0.05 indicating that the difference between the corresponding data sets were all statistically significant. A similar test called the analysis of variance test (ANOVA) can be used instead of the t-test to determine statistical significance of data collected for the icon colour, icon location and icon alert method test results (1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> scenarios). The results of the ANOVA test on these three visual variable data sets revealed a “P” value for each scenario which were less than the 0.05 standard of significance: icon colour  $P = 2.18E-21$ , icon location  $P = 6.77E-09$  and icon alert method  $P = 4.09E-10$ . Therefore, the ANOVA statistical analysis of these three visual variable data sets, and the t-tests performed on the slope angle indicator test data sets indicated that the results were all significantly significant.

## **5.0 DISCUSSION**

The results of the comprehensive data analysis and insights from the literature review generated a list of design recommendations and barriers to consider when developing an optimal AR headset and icon system for downhill winter athletes, to help improve their visual perception and spatial awareness. The design recommendations generated from the data analysis have been divided into two groups: visual display design recommendations and physical design recommendations. The visual display design recommendations consist of optimal icon colours, icon locations in the field of view and icon alerts, while the physical design recommendations refer to the physical form and manufacturing of an optimal headset display. Limitations related to the research study and the equipment used during testing were also identified and explained.

### **5.1 Visual Interface Design Recommendations**

When developing an icon and interface to be displayed via a headset for downhill winter athletes, specific variables related to visual perception such as the icon colour, location and movement can have a significant effect on the end-user's perception of the icons. Based on the results of the data collected, the orange coloured icon was ranked by participants, in terms of visibility and clarity, as the best overall (mean = 2.91), followed closely by the red icon in second (mean = 2.94) and the green icon in third (mean = 2.97). 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. In a paper on military heads-up-displays, it is identified that, "the green colour around 550 nm falls at the peak of the eye's photopic response, meaning it is generally the most effective colour for detection"

(Nicholl, 2014, pg. 7) which is supported by the green coloured icon results. This could be because colours like orange, red and green are heavily contrasted with the environmental elements of a ski hill such as snow, ice and the sky making these coloured icons easier to distinguish with a quick glance. 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 many outdoor cool-blue and white colours during the downhill winter simulation. These typical cool-blue, winter colours that make up background elements like the blue sky, the white snow, and the ice-covered trees, could potentially interfere with the visibility and perception of cool-blue and purple coloured icons, however additional studies would have to be conducted to confirm this hypothesis. Another way to optimize the colour of a display icon to ensure that every athlete can read the information clearly is to implement customization of the icon and allow the end-user to pick the icon colour that works best for them. This headset feature could be useful for people who are colour blind, or have some sort of vision impairment and cannot see certain colours, or for changing the icon colour based on the time of day or amount of sunlight available (ex. day time or night time, bright sunny day or dark cloudy day).

Another important variable related to the visual perception of an icon is its location in the field-of-view while wearing a headset. The results showed that the icon located in the top-right corner, of the field-of-view was preferred and ranked by participants as the best location overall (mean = 2.15), followed by the bottom-right in second (mean = 2.53) and the top-left (mean = 2.74) in

third. The icon located in the centre of the field-of-view (mean = 3.41) and the bottom-left icon location (mean = 3.65) were ranked fourth and fifth respectively and were above a 3.0 average, which indicated that these locations were the least favoured by participants. These results suggested that on 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 in 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”. Since most downhill winter athletes usually look down at the ground, or terrain in front of them while riding (to avoid moguls, ice patches or debris) having the icon in the bottom level could visually obstruct the terrain features or distract the end-user. Therefore, having an icon displayed in the top-level of the field of view would allow the athlete to change their focus away from the ground, to quickly glance up at the displayed info in the icon and then return their gaze to the hill. In a study by Pascale (2018) where participants attempted to detect stimuli displayed in the peripherally on either a computer monitor or a monocular lens the results indicated that for the head-mounted-display, “peripheral stimuli were less distinct and when the stimuli were presented further into the periphery” the, “effect increases as stimuli are presented further in the periphery, but can be ameliorated to a degree by using high-contrast stimuli”. This study indicated that there was an optimal area of peripheral vision to display icons in the field-of-view

while wearing a headset display, and when information is projected outside of this area it can be undetectable but could become more detectable with the use of a high contrast colour. Based off the results and research presented having an icon displayed in the top peripheral level, in the field-of-view appears to be most efficient and unobtrusive for viewing, however additional studies would have to be conducted to confirm this.

The final variable tested was the icon alert method, which was 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. Based on this data the most effective way to quickly capture the visual attention of a downhill winter athlete wearing a headset was to utilize a bright coloured icon that will contrast with the external environment and make the icon flash or blink in the user's peripheral vision. In a study by Bartram et al. (2001, pg. 164) on how efficiently visual motion cues were detected and how distracting they were in different contexts the results showed that, "motion shape of the icon not frequency has a major effect on detection and distraction," and that, "travelling motions were the most quickly detected but more distracting than anchored motion, but blinking (especially slow blinking) was the least distracting". The results from this study support the data provided by the participants whom ranked the colour changing and blinking icon alert methods as most effective to obtain the participant's attention while also not being overly distracting or obtrusive. Although the colour red was used for this icon alert test, the use of any icon colour that effectively contrasts the

background environment will likely, capture the user's attention in a similar way. The results of the same Bartram et al. (2001) study, "showed that the percentage of undetected targets increased dramatically from 6% to 25% with the peripheral colour targets, whereas the failure to detect with motion was less than 2% in both near and far field," suggesting that icons with only colour but no motion went undetected more often than icons with only motion in the peripheral. Thus, 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 study. 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 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.

## **5.2 Recommendations for the Physical Design**

The physical design recommendations to consider to optimize an AR headset with an icon interface displayed in the field-of-view for a downhill winter athlete are a combination of both participant statements collected during this research study and a review of current AR headsets available to consumers. 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-200™ AR headset that was worn by participants during this thesis study was evaluated, and 79% of participants agreed that the Moverio BT-200™ felt natural and comfortable to wear. This results suggested that there is an opportunity for improvement to make the AR headset more comfortable and the interaction of viewing the interface more natural for users, as 21% of participants thought using the Moverio BT-200™ during the simulations was both uncomfortable and unnatural.

There are number of ways to increase the comfort of a headset. Firstly, reducing the weight of the AR headset by using lightweight components, such as carbon fibre, and distributing the weight of the headset more evenly throughout the main body of the device, which could help to improve the athlete's balance and head position while wearing the AR headset. Secondly to increase athlete comfort the AR headset design should be adjustable instead of one-size-fits-all, which could be achieved with an adjustable elastic strap like standard ski goggles or adjustable glasses arms and bridge segments, similar to, the Moverio BT-200™ headset used by participants in the simulation experience testing. The size of the headset display lens could also be altered to improve comfort and natural viewing by extending the lens past the edges of peripheral vision, giving the field-of-view a larger surface area than standard ski goggles and more space to display an unobtrusive icon with information. This could allow for an icon to be displayed further back in the peripheral vision and out of the line of sight until required, resulting in less occlusion and distractions.

### **5.3 Design Barriers**

The results of the data analysis also generated a list of design barriers or issues that should be considered when developing an optimized AR headset and icon display system to improve the athlete's visual perception and awareness during downhill winter activities. One of the most prominent barriers for designing an AR headset for this downhill winter context is how to efficiently conduct a training procedure and instruction on how to effectively use the headset and all its features. Unlike other consumer tech products which will often come with a user manual and are mainly used in stationary and less dynamic context making them easy to use. AR headsets designed for downhill winter athletes require the ability to be used in the cold outdoors in a high-speed environment. This means that AR headset users will need to receive sufficient training to understand how to properly use the AR headset and all its associated functions prior to using it on a real ski hill. Thus, end-users of an AR headset will need to use a relatively easy hill to explore the AR headset's functions and become comfortable and familiar with the new technology to ensure proper use in the future.

A secondary design barrier that should be considered when designing an optimized AR headset for downhill winter athletes is developing an adaptable headset design. Due to the wide range and sizes of potential end-users, the headset would have to be designed to be ergonomically comfortable yet also easily adjustable to allow for use. The actual transparent headset display lens, where the information is projected, would likely be one standard size to reduce the cost of manufacturing. Therefore, the adjustability of the headset is key, so it can be used by different size and ages of people including small children, teenagers, adults and the elderly.

## 5.4 Study Limitations

Due to the design of this research study, which attempted to simulate a downhill winter environment and experience for the participants, there are some limitations related to the study because the participants were not exposed to real outdoor winter conditions while interacting with the headset and icon. However, 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. The limitations related to the thesis study were divided into two different categories: 1) environmental limitations and 2) technological limitations.

The first environmental limitation related to this study was the simulation room temperature of 21°C which was warm compared to more realistic cold, 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 a limitation, although some natural light came from windows, mostly overhead artificial florescent bulbs provided white light to participants. For 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.

As with any simulation training, there were some technological 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-200™ 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. The Moverio BT-200™ 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. Another limitation was the AR headsets 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. Finally, 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 hardware and software used in this study was the best that was readily available to use for participant evaluation.

The slope changing platform designed for the study also presented a few 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. Although devices that could raise and lower the slope changing platform at different speeds exist, they were deemed too expensive for this study and not required to simulate the changing angle for participants. The platform also required the primary researcher to raise and lower the platform using a remotely using a hand-held controller, instead of a computer system such as an Arduino™ controller which would have required extensive and costly programming. 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 a snowboard which would have made the simulation feel more realistic.

## 6.0 CONCLUSION

While participating in downhill winter sports, such as, “alpine ski racing, visual perception is obviously challenged by the high speed, the immense impact of forces, and occasionally by a rough and bumpy race track” (Schläppi et al., 2016, pg. 201). 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, which may improve their visual perception, spatial awareness and prevent injury (Figure 6-1). Through the experience simulation testing results, participant post-test comments and literature review, answers to the primary and secondary research questions were reached, based on both the qualitative and quantitative data analyzed.

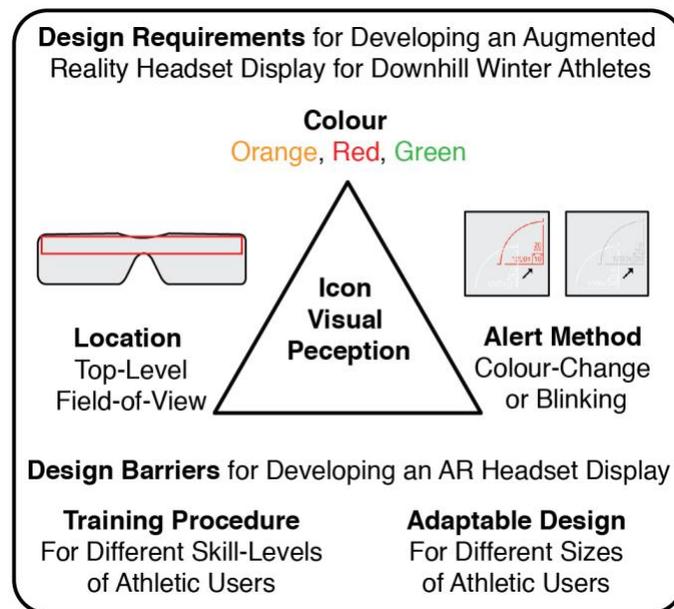
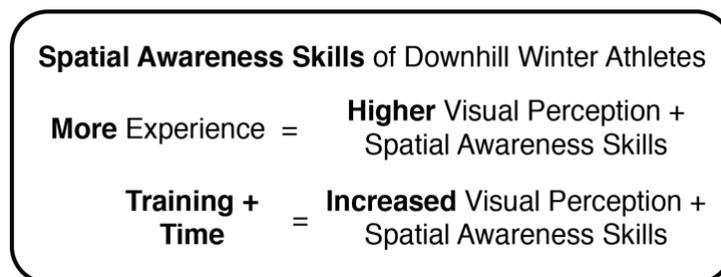


Figure 6-1. Design Requirements and Barriers for Developing an AR Display for Downhill Winter Athletes

Insights from athlete participants, and quantitative results from the simulation testing helped to address the first of the secondary questions: *can downhill winter athletes benefit from access to spatial orientation data and other important athletic information during a physical activity?* It was determined that downhill winter athletes could benefit from access to spatial orientation and

other important data during an activity. This was indicated in the post-test survey where all 34 participants selected that it was either likely or very-likely that the icon helped them to determine the slope more quickly and accurately. In the same post-test survey the majority of the participants (31 participants or 91%) indicated that it would be useful (20 participants or 59%) or very-useful (11 participants or 32%) to have access to data on spatial orientation and other athletic information while riding. Finally, the quantitative data also revealed that the icon assistance greatly improved the accuracy of participant responses. With no-icon, the average response for each of the 4 angle intervals was incorrect and over the actual angle by approximately 2 times or more, but with-icon assistance the average response for each of the 3 angle intervals was within 0.5° or less of the actual angle. The data showed that most participants could not determine the slope angle using only their visual and spatial awareness skills, however with the proper training techniques and time devoted, athletes can improve these skills. A higher level of ski or snowboard experience results in a higher level of visual perception and spatial awareness skills (Figure 6-2). This will lead to an improvement in athlete performance and reduce the potential for injury due to a physical error or distraction, as higher skill means more precision, less errors and less injury. One expert participant (lvl.8) said “I work in the ski industry, making educated guesses about slope information much easier,” indicating that over time he developed his visual and spatial awareness skills allowing him to estimate slope angles.



*Figure 6-2. Spatial Awareness Skills of Downhill Winter Athletes*

However, post-test survey results and some participant interview comments indicated that downhill winter athletes of different skill levels may benefit from this technology more than others. For instance, beginner level athletes would likely benefit the least wearing an AR headset during activity, as they are learning to ride while focusing on their technique and may become confused or overwhelmed by the information displayed. In similar way, competitive or professional level athletes have so much experience that they may not require any data from the icon, as they might be familiar with the course, slope angles and may be able to gauge and monitor their spatial orientation and speed using skills they have developed over time. This result suggests that intermediate and expert level athletes would benefit more from access to spatial orientation data transmitted by a headset display during a winter sport activity (Figure 6-3).

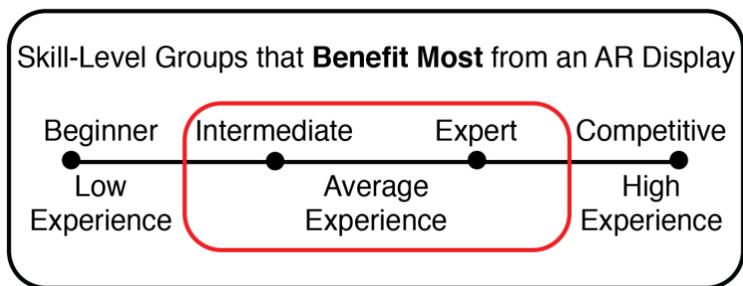


Figure 6-3. Skill Level Groups that Benefit Most from an AR Display

Participant insights and responses to questions within the post-test survey also helped to answer the second of the secondary research questions: *determine how sensory modalities and technologies can be best utilized to transmit unobtrusive data to the athletes?* 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 an 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

for this task. In another question, participants were asked to rank all five senses from best (rank 1) to worst (rank 5) and the results showed that sight had the highest average ranking of all the five senses (1.21). Finally, when asked if the visual modality was best suited for downhill winter activities, 30 participants (88%) selected “yes” the visual modality was best suited, reinforcing that the sense of sight was perceived by participants as the best way to receive the information.

Quantitative results from the testing and qualitative responses from the post-test survey helped to identify the icon colour, location in the field-of-view and visual alert that participants preferred for viewing, which answered the final secondary research question: *what visual format is most effective to deliver the data to the athletes?* 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-colour 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. These colours, locations and icon alerts that the participants preferred helped to inform the visual design recommendations for developing an icon for an augmented reality headset display.

The updated literature review research map shown below (Figure 6-4) indicates the different topics researched during the literature review with the addition of the new knowledge generated from the results of this research study, identified by the bubbles with dashed borders. The results of this study helped to identify design requirements and barriers for developing a headset display for downhill winter athletes. The results also identified that intermediate and expert level athletes would benefit from using the headset more than beginner or competitive level athletes, and that spatial awareness skills can be strengthened and improved over time with training.

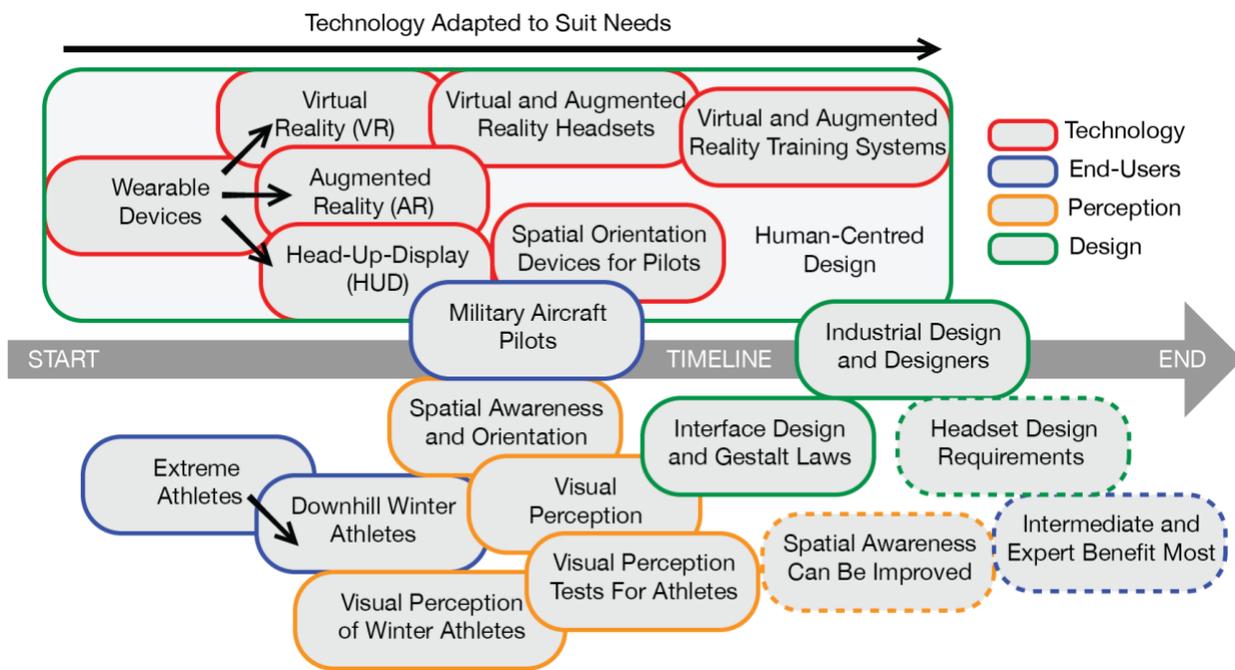


Figure 6-4. Updated Literature Review Research Map with New Knowledge Generation

## 7.0 FUTURE RESEARCH

A future opportunity for research based on the results of this study, would be to test and validate the results obtained from the simulations used in this study, in an outdoor ski hill environment.

The icon tested during the simulations generated useful results while providing participants with a shared experience, but the headset and icon system would likely perform differently in an winter environment with cold temperatures, wind, moisture and variable light conditions.

A second future research opportunity would be to evaluate the downhill winter athlete's ability to interpret the icon while in a competitive scenario, such as downhill race or while performing aerial maneuvers during a freestyle competition. These tests would be conducted outdoors on a ski hill during a competitive race or with participants performing aerial maneuvers off a specially constructed jump, to evaluate if the headset interface helps to improve the athlete's spatial awareness and physical repeatability while competing or performing aerial maneuvers.

A third future research opportunity would be to utilize 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. There are many other sports that utilize gravitational force to propel the athlete down a hill or track at high-speeds including cycling, downhill mountain biking, and ice track sports like bobsled, luge and skeleton. The slope changing platform could be altered and the simulation video changed to create a downhill mountain biking or bobsled environment. The adapted system could be used by athletes of a different sport to evaluate the usability and effectiveness of a headset display and determine if the internal and external visual perception factors are transferable across different sports.

A fourth and final future research opportunity would be to assess current technologies and materials that could be incorporated into the design and of a usable headset system, moving towards a final product as opposed to a prototype for testing. This could include researching and sourcing different materials for the transparent display lens, durable and weather resistant materials for the hard, exterior housing of the device, compact and rechargeable batteries to power the device and advanced computer hardware and sensors to control the device.

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## 9.0 APPENDICES

### Appendix A.

#### **Improving Visual Perception with Headset Displays in Downhill Winter Sports**

#### **Would you like to participate in research study, related to athletes interpreting information displayed by augmented reality headsets?**

My name is Darren O'Neill and I am a Master's of Design student at Carleton University. I am working on research study related to utilizing augmented reality glasses to display data to downhill winter athletes while they participate in sports, under the supervision of Professor Stephen Field and Professor Ali Arya. I am investigating if athletes can benefit from access to spatial orientation data during an activity, determine how sensory modalities and technologies are best utilized to transmit unobtrusive data, and evaluate what format is most effective to deliver the data to the athletes, which may improve performance and reduce injury.

#### **To be eligible for this research study, participants must fit the following criteria:**

- Currently participate in either downhill skiing or snowboarding at an at a beginner to expert skill level (participants with no experience will not accepted for this study)
- Able bodied, good vision, no injuries or disabilities that could negatively affect balance
- All participants must be within the required age range of 18 – 55 years

All participation in the research study is voluntary and can be withdrawn at any time if required. The participants in this study will receive food and refreshments, but no financial compensation. Photos and video recordings will be taken during the study, with the participant's consent.

**If you are interested in participating in this research study, please email [darrenoneill@cmail.carleton.ca](mailto:darrenoneill@cmail.carleton.ca) for a full recruitment notice.**

The ethics protocol for this project was reviewed and cleared by the Carleton University Research Ethics Board. Should you have any ethical concerns please contact: Dr. Bernadette Campbell, Chair, Carleton University Research Ethics Board-B (by phone: 613-520-2600 ext. 4085 or by email: [ethics@carleton.ca](mailto:ethics@carleton.ca)). For all other questions, please contact the researcher.

## Appendix B.

### Consent Form

**Title:** Improving the Visual Perception of Downhill Winter Athletes with Headset Displays

**Date of ethics clearance:** July 11<sup>th</sup>, 2018

**Ethics Clearance for the Collection of Data Expires:** July 31<sup>st</sup>, 2019

I \_\_\_\_\_, choose to participate in a study on improving the visual perception of downhill winter athletes by using augmented reality headsets to display data on an athlete's spatial orientation, during an activity. The aim of this study is to evaluate which visual display formats are most effective, and if a headset interface can enhance spatial awareness abilities to help reduce error and potential injury.

#### **Purpose:**

My study is looking to investigate if downhill winter athletes can benefit from access to spatial orientation data during activity, determine how sensory modalities and technologies are best utilized to transmit the data, and evaluate which visual format is most effective to deliver the data to the athletes. The objective is to provide the participant with an augmented reality headset which displays an unobtrusive interface icon, with important athletic data (speed, slope angle, altitude, etc.). The 4 visual variables being tested with the headset are; icon colour, icon location, icon alert method and icon slope angle indication. The platform that the participant stands on during the experiment will articulate up and down, changing its angle in sync with the slope angle of the simulation video. The participant will be asked to view and evaluate the icon's changing visual variables to determine which format and attributes are best suited for a downhill winter athlete.

#### **Research Personnel:**

The primary researcher in this study is a Carleton Graduate Student working under the supervision of Professor Stephen Field from Carleton University's School of Industrial Design, and co-supervisor Professor Ali Arya from Carleton University's School of Information Technology, both in the Faculty of Engineering and Design.

#### **Task Requirements:**

The study involves you standing in a skiing or snowboarding stance on platform that changes angles between 0°-25°, while watching a simulation video, and viewing different visual icons and cues displayed on AR (augmented reality) headset. You must be between the ages of 18-55, have experience downhill skiing or snowboarding at least once at a beginner to expert level, be in good physical condition with no major muscular disabilities and have no major vision issues to participate in this study. During the observations, we would appreciate your consent to take video with audio relevant to the study and will ensure your identity is concealed. Before the testing session we will record certain body segment lengths and ask you to fill out a pre-test survey to obtain demographic data and your level of experience. At the end of the session, we will ask you to fill out a post-test survey and answer some questions.

After the testing is completed, some of the participants with varying skill levels will be selected to participate in a collaborative design charrette (workshop) with coaches, industry experts and designers (facilitators). Participants of the charrette will be split into groups of 4 people, each with a different downhill winter sport background, and asked to first review and discuss the results of the previous individual headset testing sessions. The groups will then be asked to individually sketch 2 headset interface concepts during a quick ideation session and present them to the other group members. Finally, the groups will each develop a list of design recommendations for headsets designed specifically for downhill winter athletes and present their findings to the other groups. The collaborative design charrette will end with a short debriefing and a period for questions and comments. The entire 2-hour charrette will be video recorded for later analysis, with participant consent.

**Time Required:**

The entire individual test session will take approximately 30 minutes, to complete the 4 test sessions. If you are selected to participate, the phase 4: group design charrette will take approximately 2-hours to complete, during which food and refreshments will be provided.

**Right to Withdraw/Compensation:**

You have the right to end your participation in the study at any time, for any reason, up until October 30th, 2018. You can withdraw from the study at any time by directly verbally requesting to withdrawal, phoning or emailing the research supervisor. If you withdraw from the study, all information you have provided will be immediately destroyed. The participants will receive no financial compensation but will receive food and refreshments.

**Potential Risk/Discomfort:**

You will experience no physical risk or discomfort during this study, as there are very low mechanical and electrical connections to the participant. The only electrical instrument physically touching the participant will be a commercially available and low voltage Moverio BT-200 AR (augmented reality) headset, all other instruments are external to the participant. All participants will be standing on the testing apparatus platform, either in the standard downhill skiing or snowboarding stance, while secured to the padded guard rail with a safety harness for the duration of the study. During the study, participants must look directly at the ski race simulation video projected onto the screen while simultaneously viewing and interacting with a designed interface displayed in the Moverio Bt-200 glasses. The interface in the glasses displays important variables (speed, slope angle, vertical altitude) and changes in sync with the simulation video. Similarly, the testing platform articulates up and down with a remote controlled electric car jack to change the slope angle in sync with the video. This is much like standing on an angled floor while wearing glasses and watching a movie, and will not cause the participants any visual or physical discomfort.

**Anonymity/Confidentiality:**

During the project, physical notes will be transcribed to a digital file and both mediums will only contain anonymized references to individuals. The physical files will be destroyed once they are transferred to digital documentation. It is mandatory that all participants consent to have photos and videos taken of them, but all physiological data, raw video footage and photographs with faces and other defining features will be stored on a password protected laptop computer with an encrypted drive. All video and photographs included in reports and publication will de-identify participants by blurring faces using editing software.

**Data Storage:**

After the study is completed all data files will be transferred to an encrypted external hard drive, which will be stored in a locked cabinet only accessible by the research team, and the data will be deleted from the laptop computer. Once the project is completed, all the data will be kept for 10 years and potentially used for other research projects on this same topic. At the end of 10 years, all data will be destroyed.

The ethics protocol for this study was reviewed and cleared by the Carleton University Research Ethics Board. Should you have any ethical concerns, please contact:

Dr. Bernadette Campbell, Chair, Carleton University Research Ethics Board-B  
(by phone: 613-520-2600 ext. 4085 or by email: [ethics@carleton.ca](mailto:ethics@carleton.ca)).  
For all other questions about the study, please contact the researcher.

**Researcher contact information:**

Name: Darren O'Neill  
Department: School of Industrial Design  
Carleton University  
Email: [darren.oneill@carleton.ca](mailto:darren.oneill@carleton.ca)

**Supervisor contact information:**

Name: Professor Stephen Field  
Department: School of Industrial Design  
Carleton University  
Tel: 613.520.2600, ext. 8371  
Email: [stephen.field@carleton.ca](mailto:stephen.field@carleton.ca)

**Co-supervisor contact information:**

Name: Ali Arya  
Department: School of Information Technology  
Carleton University  
Tel: 613.520.2600, ext. 4184  
Email: [ali.arya@carleton.ca](mailto:ali.arya@carleton.ca)

Do you agree to observation of you in the testing environment? \_\_\_Yes \_\_\_No

Do you agree to photos of you being taken? \_\_\_Yes \_\_\_No

Do you agree to videos of you being recorded with audio? \_\_\_Yes \_\_\_No

Do you agree to having various body segments measured? \_\_\_Yes \_\_\_No

If yes, please provide an email address where we can reach you to arrange a convenient time for testing on campus:

\_\_\_\_\_

\_\_\_\_\_  
Signature of participant

\_\_\_\_\_  
Date

\_\_\_\_\_  
Signature of researcher

\_\_\_\_\_  
Date

## Appendix C.

### Pre-Test Survey

1. Participant (e.g. P1): \_\_\_\_\_
2. Age: \_\_\_\_\_
3. Height: \_\_\_\_\_
4. Sex: **Male**\_\_ / **Female**\_\_ /
5. What is your downhill winter sport of choice?  
**Skiing**\_\_ / **Snowboarding**\_\_ /
6. What type of downhill skiing or snowboarding do you primarily participate in?  
**Leisure**\_\_ / **Slalom**\_\_ / **Back Country**\_\_ / **Terrain Park**\_\_ / **Snow-Cross**\_\_ /
7. Has a professionally licensed instructor ever given you lessons for this sport?  
**Yes** \_\_ / **No**\_\_ /
8. If yes, how many lessons in total did you receive from an instructor for this sport?  
**1 Lesson** \_\_ / **2-3 Lessons**\_\_ / **4-5 Lessons**\_\_ / **6+ Lessons** \_\_ / **N.A.** \_\_ /
9. Are you a professionally licensed instructor, who has given lessons for this sport?  
**Yes** \_\_ / **No**\_\_ /
10. If you are a licensed instructor, for how many years have you taught lessons?  
**1 Year** \_\_ / **2-4 Years**\_\_ / **5-9 Years**\_\_ / **10+ Years** \_\_ / **N.A.** \_\_ /
11. Have you ever competed in an organized competition or race in this sport?  
**Yes** \_\_ / **No**\_\_ /
12. If yes, how many competitions or races have you competed in?  
**1 Comp.** \_\_ / **2-4 Comps.**\_\_ / **5-9 Comps.**\_\_ / **10+ Comps.** \_\_ / **N.A.** \_\_ /

13. How often do you use wearable tech devices during athletic activities?

**Very Often \_\_ / Sometimes\_\_ / Rarely\_\_ / Never\_\_ /**

14. If yes, which wearable tech devices have you used during an athletic activity?

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15. How often do you use virtual reality (VR) headsets during an activity or game?

**Very Often \_\_ / Sometimes\_\_ / Rarely\_\_ / Never\_\_ /**

16. If yes, which virtual reality (VR) devices have you used for activities or games?

---

17. Do you know what augmented reality (AR) is?

**Yes \_\_ / No\_\_ /**

18. If yes, then please define what “augmented reality” means in your own words.

---

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19. How often do you use augmented reality (AR) headsets for any sort of activity?

**Very Often \_\_ / Sometimes\_\_ / Rarely\_\_ / Never\_\_ /**

20. If yes, which augmented reality headsets have you used during these activities?

---

Appendix D.

**Participant Skill Level Assessment**

1. Participant (e.g. P1): \_\_\_\_\_

<b>Skill Level</b>	<b>#</b>	<b>Skiing</b>	<b>Snowboarding</b>	<b>X</b>
<b>Beginner</b> (Green)	<b>1</b>	Tried skiing once or 1 <sup>st</sup> time, rides bunny hills	Tried snowboarding once or 1 <sup>st</sup> time, rides bunny hills	
	<b>2</b>	Able to ski in a cautious wedge, tests out green terrain	Side slips on toe/heel to go left/right, test out green terrain	
	<b>3</b>	Able to make large round turns with confidence on green terrain	Able to slide left/right in control on both edges or complete an independent heel/toe turn on a green terrain	
<b>Intermediate</b> (Green) (Blue) (Easy Black)	<b>4</b>	Able to link turns with speed control and brings skis together parallel at the end of the turn on green and easier blue terrain	Able to complete a linked toe/heel turn on gentle green terrain and looking toward easy blue terrain	
	<b>5</b>	Able to ski mostly parallel but may wedge or step to start the turns, confident on green and easy blue terrain	Able to complete linked turns on toe/heel side on green and blue terrain	
	<b>6</b>	Able to use a parallel stance on smooth blue and easy black terrain and tests skills on varied terrain and varied snow conditions (ex. moguls, ice, trees)	Able to complete linked turns with minimal traverse comfortably on all blue terrain and easy black terrain, tests varied terrain and conditions (ex. moguls, ice, trees)	
<b>Expert</b> (Green) (Blue) (Black) (Hard Black) (Glades) (Park)	<b>7</b>	Able to ski with controlled parallel turns, maintaining rhythm and speed control on groomed black terrain, can ride the terrain park and some glades	Able to link turns with rhythm and flow on difficult blue and most black terrain, and can ride the terrain park and some forest glades	
	<b>8</b>	Able to ski with good technique on all terrain and snow conditions, using carved short radius turns and can perform tricks in the terrain park	Able to join instructors and ride all over the mountain on all terrain, in all snow conditions (ex. moguls, ice, trees) and can perform tricks in the terrain park	
<b>Competitive/ Professional</b> (Competes)	<b>9</b>	At expert skill level (8) and competed in ski races or competitions and may be on a national team or part of an official organization.	At expert skill level (8) and competed in snowboard races or competitions and may be on a national team or part of an official organization.	

## Appendix E.

### Post-Test Survey

1. Participant (e.g. P1): \_\_\_\_\_
2. Rank the different icon colours presented, in terms of visual perception and which were most visible and easy to read. **(1 = Best, 7 = Worst)**  
**Red\_\_ / Orange \_\_ / Yellow\_\_ / Green\_\_ / Blue\_\_ / Indigo\_\_ / Violet\_\_ /**
3. How strong of an effect does colour have on the visual perception of icons?  
**Strong Effect\_\_ / Moderate Effect\_\_ / Low Effect\_\_ / No Effect\_\_ /**
4. Rank the different icon locations, in terms of visual perception and which were most unobtrusive, non-distracting, and easy to read. **(1 = Best, 5 = Worst)**  
**Top Right\_\_ / Top Left \_\_ / Bottom Right\_\_ / Bottom Left\_\_ / Middle \_\_ /**
5. How strong of an effect does location have on the visual perception of icons?  
**Strong Effect\_\_ / Moderate Effect\_\_ / Low Effect\_\_ / No Effect\_\_ /**
6. Rank the different icon alert methods, in terms of visual perception and which were most visible, and easy to notice or get your attention. **(1 = Best, 4 = Worst)**  
**Colour Changing\_\_ / Expanding\_\_ / Flashing \_\_ / Rotating\_\_ /**
7. How strong of an effect does alert type have on the visual perception of icons?  
**Strong Effect\_\_ / Moderate Effect\_\_ / Low Effect\_\_ / No Effect\_\_ /**
8. Select the level of difficulty, related to attempting to determine the slope angle using only your spatial orientation skills and vision NOT USING the interface.  
**Very Easy\_\_ / Easy\_\_ / Moderate\_\_ / Hard\_\_ / Very Hard\_\_ /**

9. Select the level of difficulty, related to attempting to determine the slope angle USING the headset interface and displayed icon.

**Very Easy\_\_ / Easy\_\_ / Moderate\_\_ / Hard\_\_ / Very Hard\_\_ /**

10. Do you think the headset interface helped you determine slope more quickly?

**Very Likely\_\_ / Likely\_\_ / No Affect\_\_ / Unlikely\_\_ / Very Unlikely\_\_ /**

11. Do you think the headset interface helped you determine slope more accurately?

**Very Likely\_\_ / Likely\_\_ / No Affect \_\_ / Unlikely\_\_ / Very Unlikely\_\_ /**

12. While skiing/snowboarding do you think that it would be useful to have access to data on spatial orientation and other athletic data while riding or competing?

**Very Useful\_\_ / Useful\_\_ / No Affect\_\_ / Un-useful\_\_ / Very Un-useful\_\_ /**

13. What group of athletes do you think would benefit most from a headset display?

**Beginners\_\_ / Intermediate\_\_ / Experts\_\_ / Professionals\_\_ / None\_\_ /**

14. Rank the sensory modality in terms of which you think are best suited to transmit information to downhill winter athletes during an activity. **(1= Best, 5 = Worst)**

**Sight\_\_ / Hearing\_\_ / Touch\_\_ / Smell\_\_ / Taste\_\_ /**

15. Do you think that the visual modality is the best suited for transmitting this data?

**Yes\_\_ / No\_\_ /**

16. Did wearing the headset and viewing the interface feel natural and comfortable?

**Strongly Agree\_\_ / Agree\_\_ / Disagree\_\_ / Strongly Disagree \_\_ /**

17. How much did this study and testing session teach you about augmented reality?

**High Learning\_\_ / Moderate Learning\_\_ / Low Learning\_\_ / No Learning\_\_ /**

18. If you have any final comments on the testing, please indicate them below.

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# Appendix F. Icon Tutorial

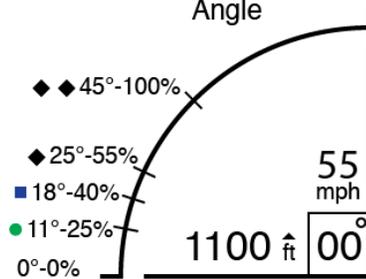
## Ski Hill Rating Scale (Grade% - Slope Angle)

**Beginner:**  
12% - 7°  
25% - 11°

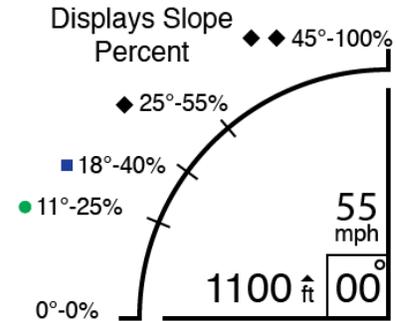
**Intermediate:**  
40% - 18°

**Expert:**  
55% - 25°  
100% - 45°

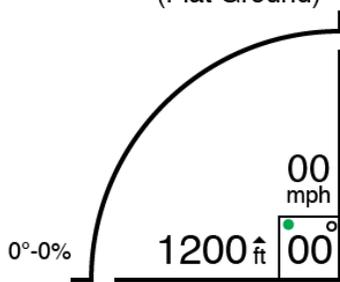
Displays Actual Angle



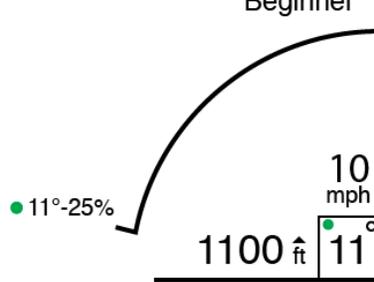
Displays Slope Percent



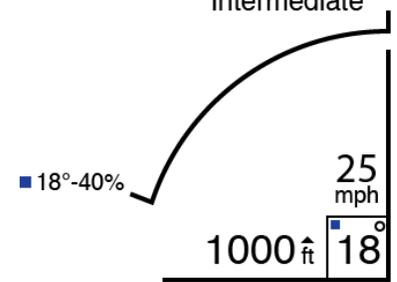
Top Of Hill  
(Flat Ground)



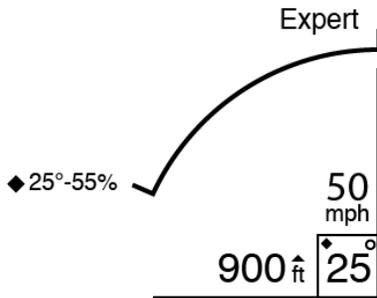
Beginner



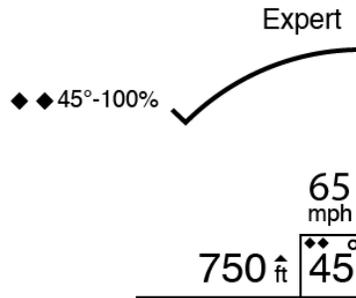
Intermediate



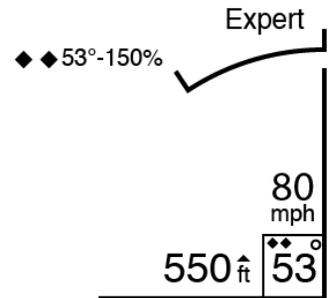
Expert



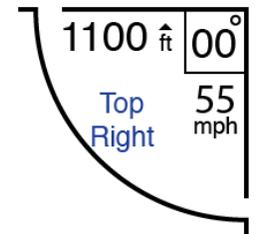
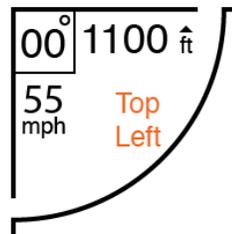
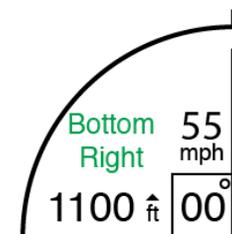
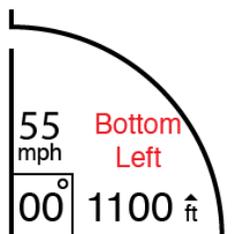
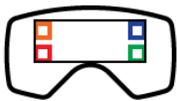
Expert



Expert



## Interface Icon Placement In The AR Glasses



## Appendix G.

### Researcher Script

#### **Pre-Test Brief, Consent Form Signing and Survey:**

Hello good morning/afternoon, my name is Darren O'Neill and I am going to be walking you through today's session. During this study, you will be wearing an augmented reality headset which displays a visual icon with data on important variables for skiers or snowboarders (speed, slope angle, vertical altitude, etc.). You must pay attention to the icons displayed by the headset, while also watching a simulation video that is being played on the screen in front you. During this the specially designed platform that you stand on will articulate up and down, changing its angle in sync with the slope angle in the video to simulate a changing mountain slope. The session should take about 30 minutes in total. If you are comfortable with me video recording you using the headset, then we will need your full written consent. Please sign the consent form provided and fill out the pre-test survey before we begin the session.

[Researcher gives the participant the Consent Form and Pre-Test Survey to fill out]

Thank you. Now the first thing that I want to make clear right away is that you cannot do anything wrong here. As you view the displayed interface I would like you to try to think out loud and honestly: say what you're looking at, what you're trying to do, and what you're thinking at that moment. I would like you to view and react to the headset interface independently, but if you have any questions about how to interact with the apparatus and interface you may ask me. I may not be able to answer them right away, since I am interested in how people function when they don't have access to someone for help. However, if you still have questions at the end of the session I will try to answer them for you. Also, if you need to take a break, or wish to end the session due to a sudden illness or emergency, please just let me know.

### **Tutorial Test Session:**

Now I will give you a short tutorial before we begin the test scenarios. First, please put on this safety harness, ensuring that it is both tight and comfortable, and step onto the platform. The four scenarios that you will be engaging in will be performed while standing so there is no need to sit down or leave the platform during the study. As I said previously, the platform you are standing on is specifically designed to raise up and down during the testing sessions, and change between the angles of  $0^{\circ}$ - $25^{\circ}$  in a safe and controlled way. This is to simulate the changing slope of a ski hill and you are to stand in a ski or snowboarding stance, with your knees bent, during the test. While the simulation video is playing and the platform is moving, you will be wearing headphones playing wind sounds and a headset which will display an icon I developed for testing and evaluation important variables of visual perception. You will be asked evaluate these icons and changing variables to determine which format and attributes are best suited for a winter sport context. Here is an image of the icon that will be displayed by the headset, there are three main variables shown: the ski hill's slope angle is displayed within the square box, the athlete's speed (mph) is above the square slope angle box and the vertical height (km) is to the left of the square slope angle box. During the first 3 scenarios, the icons will remain static, they will only change in the final 4<sup>th</sup> scenario.

During the test sessions, please refrain from bouncing up and down on the platform, or leaning side to side as it may cause the platform or the electrical components to shift around. Although there is a safety railing for you to grab onto if you are feeling scared or off-balance at any point due to the tilting platform, I will ask that you please refrain from holding onto it unless it is necessary. This study is trying to simulate realistic downhill skiing and snowboarding conditions and do to this you need to have your knees bent and arms hanging freely by your side, instead of holding onto the railing. If at any point you wish for the test session to stop due to discomfort or illness, please shout "STOP" out-loud and the researcher controlling the platform will stop the incline and return the platform to its original, flat, starting position. Please wait for researcher approval before stepping off the platform. We will now begin the testing session. Do you have any final questions or requests before we begin?

### **1<sup>st</sup> Test Session Visual Variable: Icon Colour (ROYGBIV)**

[The researcher turns on the video cameras and checks the safety harness]

For each testing segment, you will be asked to evaluate the visual perception and clarity of the icons presented to you through the display of the headset. Each test segment will evaluate 4 different variables related to visual perception: icon colour, icon location, icon alert method and icon slope angle display method. You must focus on and watch the changing icons displayed by the headset to evaluate which variables and formats are best suited for displaying information in this downhill winter sport context. For each

The 1<sup>st</sup> variable you will be evaluating today is icon colour. The icon will be displayed in the headset in the bottom right corner, and will cycle through the visible spectrum of colours that make up the rainbow (ROYGBIV). You will have 7 seconds to view each colour and evaluate how it improves or effects overall visual perception of the icon. After will be asked to rank the colours from most to least visible afterwards. I will now start the icon simulation in the headset display, I will then pass it to you to put on and it will read “adjust the headset until comfortable” for 15 seconds allowing you to adjust. Next it will read “prepare to begin” for 5 seconds before counting down “3, 2, 1” during which I will ask you to count “3, 2, 1” out loud so that I can sync the television simulation video with the icon simulation. We are about to start the session. Please remember to think out loud during the session, do you have any questions or requests before we begin?

[Starts headset icon simulation passes it to participant and starts the video simulation]

### **2<sup>nd</sup> Test Session Visual Variable: Icon Location**

The 2<sup>nd</sup> variable you will be evaluating today is icon location. The icon will be displayed in the headset and will cycle through different locations within your field-of-view, giving you 8 seconds to pause and evaluate how the location effects the overall visual perception of the icon. After you will be asked to rank the icon locations from the most unobtrusive and easy to read to least. Any final questions or requests before we begin?

[Starts headset icon simulation passes it to participant and starts the video simulation]

### **3<sup>rd</sup> Test Session Visual Variable: Icon Alert Method**

The 3<sup>rd</sup> variable you will be evaluating today is the icon alert method. The icon will be displayed in the headset and will cycle through different alert methods, giving you 8 seconds to pause and evaluate which method improves the overall visual perception of the icon. After you will be asked to rank the icon alert methods from the most visible and easy to notice to least visible. Any final questions or requests before we begin?

[Starts headset icon simulation passes it to participant and starts the video simulation]

### **4<sup>th</sup> Test Session Visual Variable: Icon Slope Angle Indication**

The 4<sup>th</sup> and final variable you will be evaluating today is icon slope angle indication. While the platform changes its angle the headset display will count down “3, 2, 1” followed by a message “determine slope angle now” prompting you to shout out what you think the platform slope angle is at that exact second. First you will attempt this with no icon in the headset, followed by a second test with the icon showing the changing slope angle. After you will be asked to rank the difficulty of determining the slope angle with and without the headset icon. Any final questions or requests before we begin?

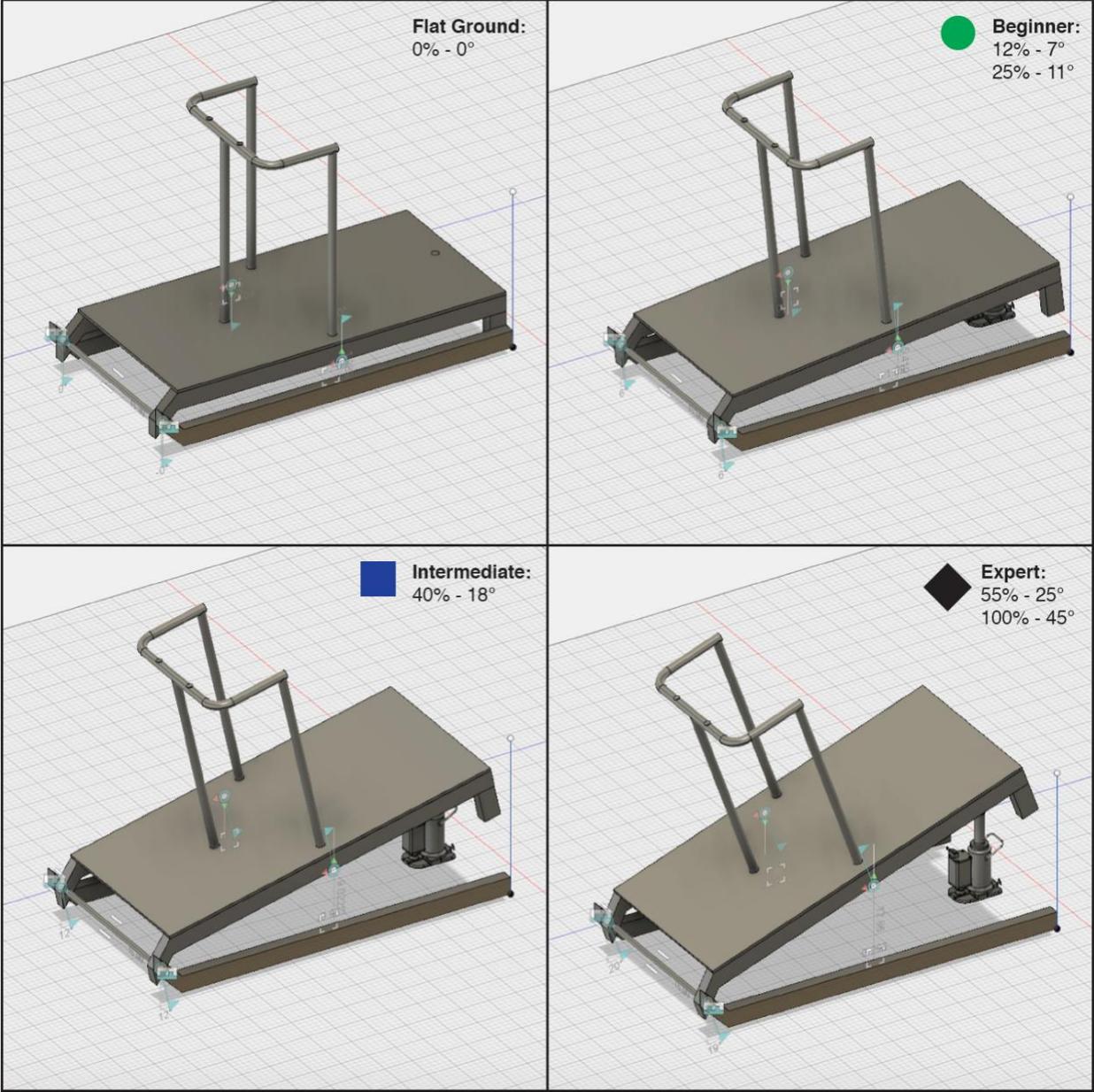
[Starts headset icon simulation passes it to participant and starts the video simulation]

Thank you for completing the testing session that was very helpful. Please fill out this post-test survey so we can better understand your experience with the interface.

[Participant removes all equipment and is given the Post-Test Survey to fill out]

Thank you for completing the post-test survey. I will now conclude the session with an opportunity for you to voice any questions, comments or concerns you may have related to the interface or the testing procedure itself. Please do not hesitate to say what is on your mind and please be honest, as this will help to make future improvements to the study. Thank you for your participation in this study. Please help yourself to some food and drink if you wish. I will be in contact with you in case I require some clarification on any of your responses.

**Appendix H. 3D CAD Model of the Slope Changing Platform**



# Appendix I. Pre-Test Survey Results - Excel Spread Sheet

Participant	Skill Level - Results	Skill Level	Pre-Test	Pre-Q1 (Qual. Results)	Pre-Q3 (Qual. Results)	Pre-Q4 (Qual. Results)	Pre-Q5 (Qual. Results)	Pre-Q6 (Qual. Results)	Pre-Q7 (Qual. Results)	Pre-Q8 (Qual. Results)	Pre-Q9 (Qual. Results)	Pre-Q10 (Qual. Results)	Pre-Q11 (Qual. Results)	Pre-Q12 (Qual. Results)	Pre-Q13 (Qual. Results)	Pre-Q14 (Qual. Results)	Pre-Q15 (Qual. Results)	Pre-Q16 (Qual. Results)	Pre-Q17 (Qual. Results)	Pre-Q18 (Qual. Results)	Pre-Q19 (Qual. Results)	Pre-Q20 (Qual. Results)
P1	Mean: 5.411765	5	52	Mean: 26.76471	54"	F	Ski	1	No	N/A	No	N/A	No	N/A	4 - Never	N/A	4 - Never	N/A	No	N/A	4 - Never	N/A
P2	Standard Error: 0.441028	8	23	Standard Error: 1.459073	51"	M	Ski	1	Yes	4 - (6+) Lesson	No	N/A	Yes	4 - 10+ Comp	4 - Never	N/A	4 - Never	N/A	No	N/A	4 - Never	N/A
P3	Median: 6.5	5	24	Median: 23.5	53"	F	Ski	1	Yes	2 - (2-3) Lesson	No	N/A	No	N/A	4 - Never	N/A	4 - Never	N/A	Yes	Doing things that aren't there	4 - Never	N/A
P4	Mode: 7	6	43	Mode: 22	61"	M	Ski	1	Yes	2 - (2-3) Lesson	No	N/A	No	N/A	4 - Never	N/A	3 - Rarely	Oculus Rift, Microsoft Holo Lens	Yes	Combination of digital artifacts or imagery with actual physical environment	3 - Rarely	Microsoft Holo Lens
P5	Standard Deviation: 2.571612	8	24	Standard Deviation: 8.507792	59"	M	Ski	4	Yes	3 - (4-5) Lesson	Yes	2 - (2-4) Years	Yes	3 - (5-9) Comp	1 - Very Often	Fitbit	4 - Never	N/A	Yes	The iron man suit display	4 - Never	N/A
P6	Sample Variance: 6.613191	1	26	Sample Variance: 72.38235	58"	M	Ski	1	No	N/A	No	N/A	No	N/A	1 - Very Often	Garmin	2 - Sometimes	Oculus Rift, Microsoft Holo Lens	Yes	Using technology to seamlessly facilitate real world experiences	2 - Sometimes	Microsoft Holo Lens
P7	Kurtosis: -0.99438	2	26	Kurtosis: 4.648492	57"	M	Ski	1	No	N/A	No	N/A	No	N/A	4 - Never	N/A	3 - Rarely	Oculus Rift	Yes	Device that takes pre-existing objects or environment and digitally manipulate it	4 - Never	N/A
P8	Skewness: -0.68148	1	28	Skewness: 2.21552	57"	M	Snowboard	1	No	N/A	No	N/A	No	N/A	4 - Never	N/A	3 - Rarely	Oculus Rift	Yes	Provides a layer of technology to add data or imaging into your vision or simulation	4 - Never	N/A
P9	Range: 8	8	54	Range: 35	57"	M	Ski	1	No	N/A	No	N/A	No	N/A	2 - Sometimes	GoPro, step counter on iPhone	4 - Never	N/A	No	N/A	4 - Never	N/A
P10	Minimum: 1	3	26	Minimum: 19	53"	F	Snowboard	1	No	N/A	No	N/A	No	N/A	4 - Never	N/A	4 - Never	N/A	No	N/A	4 - Never	N/A
P11	Maximum: 9	1	24	Maximum: 54	54"	F	Snowboard	1	Yes	1 - 1 Lesson	No	N/A	No	N/A	2 - Sometimes	Fitbit, GoPro	2 - Sometimes	Samsung Gear	Yes	Alternative Reality	3 - Rarely	Samsung Gear
P12	Sum: 184	6	25	Sum: 893	62"	M	Ski	1	No	N/A	No	N/A	No	N/A	4 - Never	N/A	3 - Rarely	Oculus Rift	Yes	Overlays information onto the real world for the user often using transparent displays	4 - Never	N/A
P13	Count: 34	8	25	Count: 34	51"	M	Snowboard	4	Yes	4 - (6+) Lesson	No	N/A	Yes	2 - (2-4) Comp	3 - Rarely	GoPro	4 - Never	N/A	No	N/A	4 - Never	N/A
P14		7	21		57"	F	Ski	1	Yes	4 - (6+) Lesson	No	N/A	Yes	2 - (2-4) Comp	3 - Rarely	iPhone Health App	3 - Rarely	Oculus Rift	Yes	Superimposing 3D images into the real world	4 - Never	N/A
P15		1	32		51"	F	Snowboard	1	Yes	2 - (2-3) Lesson	No	N/A	No	N/A	4 - Never	N/A	4 - Never	N/A	No	N/A	4 - Never	N/A
P16		7	24		58"	M	Snowboard	1	Yes	4 - (6+) Lesson	No	N/A	No	N/A	4 - Never	N/A	4 - Never	N/A	Yes	Overlying virtual images on a real background	4 - Never	N/A
P17		7	20		55"	F	Ski	3	No	N/A	No	N/A	No	N/A	3 - Rarely	Fitbit	3 - Rarely	Oculus Rift	No	N/A	4 - Never	N/A
P18		7	23		54"	F	Snowboard	1	No	N/A	No	N/A	No	N/A	3 - Rarely	iPhone Health App	4 - Never	N/A	Yes	A computer designed world in which someone feels like what they are seeing is real	4 - Never	N/A
P19		6	26		63"	M	Snowboard	1	No	N/A	No	N/A	No	N/A	1 - Very Often	Cellphone app for mountain bike	3 - Rarely	HTC Vive	Yes	Alternate Reality, another reality that does not exist in the real world	4 - Never	N/A
P20		1	33		54"	F	Snowboard	1	No	N/A	No	N/A	No	N/A	1 - Very Often	Smart watch (apple watch)	3 - Rarely	HTC Vive	Yes	Augmented reality adds an overlay to real life things including additional related info (for example, map route over image captured by camera)	4 - Never	N/A
P21		9	22		54"	F	Ski	2	Yes	4 - (6+) Lesson	Yes	2 - (2-4) Years	Yes	4 - 10+ Comp	4 - Never	N/A	4 - Never	N/A	Yes	Allows you to see more information as you wear the device	4 - Never	N/A
P22		7	22		510"	M	Ski	1	No	N/A	No	N/A	No	N/A	4 - Never	N/A	4 - Never	N/A	Yes	A recreation of life events which is simulated for research, enjoyment or to be health maintenance	4 - Never	N/A
P23		2	23		54"	F	Ski	1	Yes	2 - (2-3) Lesson	No	N/A	No	N/A	4 - Never	N/A	3 - Rarely	VR headset	Yes	Augmented reality is being able to see 2D images in a 3D space	4 - Never	N/A
P24		7	21		51"	M	Ski	1	Yes	4 - (6+) Lesson	No	N/A	Yes	2 - (2-4) Comp	1 - Very Often	Headphone speakers - built in	4 - Never	N/A	Yes	Taking the reality (visual reality) and adding ques/interface to assist the user.	4 - Never	N/A
P25		8	22		6'	M	Snowboard	4	Yes	2 - (2-3) Lesson	No	N/A	Yes	2 - (2-4) Comp	4 - Never	N/A	3 - Rarely	Phone mounted in a VR headset for a VR tour	Yes	Augmenting the real world with a virtual device to add in virtual elements	4 - Never	N/A
P26		3	19		58"	F	Ski	1	Yes	2 - (2-3) Lesson	No	N/A	No	N/A	3 - Rarely	iPhone Health App	3 - Rarely	Oculus Rift and Samsung Gear VR headset	No	N/A	4 - Never	N/A
P27		7	22		59"	F	Ski	1	No	N/A	No	N/A	No	N/A	2 - Sometimes	GoPro, step counter on iPhone	4 - Never	N/A	No	N/A	4 - Never	N/A
P28		3	20		62"	M	Snowboard	1	No	N/A	No	N/A	No	N/A	3 - Rarely	Strava app on iPhone (biking)	3 - Rarely	Oculus Rift demo	Yes	Overlying elements in reality to create immersive experiences	3 - Rarely	Pokemon Go
P29		7	21		55"	F	Snowboard	1	No	N/A	No	N/A	No	N/A	4 - Never	N/A	4 - Never	N/A	No	N/A	4 - Never	N/A
P30		7	20		59"	M	Snowboard	4	Yes	4 - (6+) Lesson	No	N/A	No	N/A	2 - Sometimes	Fitbit, occasionally iPhone step counter	3 - Rarely	Oculus Rift	Yes	Augmented reality is the insertion of digital experiences into regular everyday real life experiences.	1 - Very Often	Pokemon Go
P31		8	22		52"	F	Snowboard	3	Yes	2 - (2-3) Lesson	Yes	2 - (2-4) Years	No	N/A	3 - Rarely	iPhone Health App	3 - Rarely	Oculus Rift and Samsung Gear VR	Yes	A simulated reality, different from our own that we can see through wearable devices.	4 - Never	N/A
P32		6	22		59"	F	Snowboard	1	Yes	2 - (2-3) Lesson	No	N/A	No	N/A	4 - Never	N/A	4 - Never	N/A	No	N/A	4 - Never	N/A
P33		5	38		510"	M	Snowboard	1	No	N/A	No	N/A	Yes	1 - 1 Comp	2 - Sometimes	Listening to music on iPhone while skateing	3 - Rarely	Oculus Rift for user testing	Yes	Matching surreal with real environments	4 - Never	N/A
P34		7	20		62"	M	Snowboard	3	No	N/A	No	N/A	No	N/A	3 - Rarely	Watch to test heart rate	3 - Rarely	Oculus Rift, HTC Vive, Google Cardboard	Yes	"Popups" or indicators that provide useful information in everyday life	4 - Never	N/A

## Appendix J. Slope Angle Determination Test Results - Excel Spread Sheet

Participants	1st Angle(N)	1st Angle(N) - Results	2nd Angle(N)	2nd Angle(N) - Results	3rd Angle(N)	3rd Angle(N) - Results	4th Angle(N)	4th Angle(N) - Results	1st Angle(Con)	1st Angle(Con) - Results	2nd Angle(Con)	2nd Angle(Con) - Results	3rd Angle(Con)	3rd Angle(Con) - Results
P1	8	Mean 10.97	12	Mean 39.65	20	Mean 44.94	15	Mean 18.74	14	Mean 14.24	20	Mean 20.44	9	Mean 9.15
P2	15	Standard Error 0.89	20	Standard Error 2.75	15	Standard Error 2.99	5	Standard Error 1.71	15	Standard Error 0.21	19	Standard Error 0.50	10	Standard Error 0.06
P3	10	Median 10.00	45	Median 40.00	45	Median 45.00	15	Median 17.50	14	Median 14.00	20	Median 20.00	9	Median 9.00
P4	5	Mode 10.00	45	Mode 45.00	50	Mode 50.00	15	Mode 15.00	14	Mode 14.00	20	Mode 20.00	9	Mode 9.00
P5	10	Standard Deviation 5.18	15	Standard Deviation 15.32	23	Standard Deviation 17.44	10	Standard Deviation 9.96	13	Standard Deviation 1.23	20	Standard Deviation 2.94	9	Standard Deviation 0.36
P6	5	Sample Variance 26.88	45	Sample Variance 234.64	50	Sample Variance 304.06	15	Sample Variance 99.29	14	Sample Variance 1.52	20	Sample Variance 8.62	9	Sample Variance 0.13
P7	15	Kurtosis 0.30	30	Kurtosis -0.46	40	Kurtosis -0.44	15	Kurtosis -0.08	14	Kurtosis 29.76	20	Kurtosis 33.51	9	Kurtosis 2.50
P8	7	Skewness 0.83	40	Skewness -0.09	45	Skewness 0.01	15	Skewness 0.47	14	Skewness 5.30	20	Skewness 5.77	9	Skewness 2.09
P9	20	Range 21.00	60	Range 58.00	10	Range 70.00	5	Range 41.00	14	Range 8.00	20	Range 18.00	9	Range 1.00
P10	15	Minimum 4.00	55	Minimum 12.00	60	Minimum 10.00	30	Minimum 4.00	21	Minimum 13.00	37	Minimum 19.00	9	Minimum 9.00
P11	10	Maximum 25.00	45	Maximum 70.00	60	Maximum 80.00	25	Maximum 45.00	14	Maximum 21.00	20	Maximum 37.00	9	Maximum 10.00
P12	10	Sum 373.00	40	Sum 1229.00	50	Sum 1528.00	35	Sum 637.00	14	Sum 484.00	20	Sum 695.00	9	Sum 311.00
P13	5	Count 34.00	45	Count 31.00	55	Count 34.00	20	Count 34.00	14	Count 34.00	20	Count 34.00	9	Count 34.00
P14	10	Real Angle=5	20	Real Angle=14	40	Real Angle=20	5	Real Angle=9	14	31 people = 14 2 people = 15 1 person = 13 1 person = 21	20	31 people = 20 2 people = 19 1 person = 37	9	29 people = 9 3 people = 10
P15	10		13		75		45		14		19		9	
P16	10		60		70		30		14		20		9	
P17	10		70		80		30		14		20		9	
P18	5		40		50		20		14		20		9	
P19	10		40		35		5		14		20		9	
P20	5		N/A		25		15		14		20		10	
P21	25		65		55		10		14		20		9	
P22	20		60		70		30		14		20		9	
P23	7		45		30		15		14		20		10	
P24	7		35		40		20		14		20		9	
P25	4		18		20		7		14		20		9	
P26	20		N/A		70		30		14		20		9	
P27	10		N/A		50		30		14		20		9	
P28	15		35		40		25		14		20		10	
P29	5		35		40		25		14		20		9	
P30	9		35		30		20		14		20		9	
P31	15		26		45		4		14		20		9	
P32	15		45		60		20		14		20		10	
P33	11		50		35		11		14		20		9	
P34	15		40		45		20		15		20		9	

# Appendix K. Icon Colour and Location Test Results - Excel Spread Sheet

Participant	Post-Questionnaire	Q2-R - Result	Q2-G - Result	Q2-Y - Result	Q2-B - Result	Q2-O - Result	Q2-P - Result	Q2-R - Result	Q2-G - Result	Q2-Y - Result	Q2-B - Result	Q2-O - Result	Q2-P - Result	Post-Questionnaire	Q2-R - Result	Q2-G - Result	Q2-Y - Result	Q2-B - Result	Q2-O - Result	Q2-P - Result	Post-Questionnaire	Q2-R - Result	Q2-G - Result	Q2-Y - Result	Q2-B - Result	Q2-O - Result	Q2-P - Result	Post-Questionnaire		
91	R.4.O.1.Y.1.G.1, B.2.1.4.V.5	Mean 3.24	Mean 3.21	Mean 3.4	Mean 2.2	Mean 4.8	Mean 4.4	Mean 4.1	Mean 4.1	Mean 4.1	Mean 4.1	Mean 4.1	Mean 4.1	1 - Strong Effect	TR-1, TL-2, BR-4, BL-3, M-5	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1 - Strong Effect
92	R.1.O.2.Y.4.G.7, B.5.1.4.V.3	Standard Error 0.31	Standard Error 0.23	Standard Error 0.35638	Standard Error 0.25	Standard Error 0.2	Standard Error 0.2	Standard Error 0.2	Standard Error 0.2	Standard Error 0.2	Standard Error 0.2	Standard Error 0.2	Standard Error 0.2	2 - Moderate Effect	TR-3, TL-1, BR-4, BL-3, M-5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2 - Moderate Effect
93	R.7.O.5.Y.1.G.2, B.3.1.4.V.6	Median 2.52	Median 3.00	Median 3.00	Median 3.00	Median 5.00	Median 6.00	Median 7.00	Median 7.00	Median 7.00	Median 7.00	Median 7.00	Median 7.00	2 - Moderate Effect	TR-2, TL-1, BR-4, BL-3, M-5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2 - Moderate Effect
94	R.7.O.4.Y.4.G.1, B.3.1.2.V.5	Mode 1.00	Mode 2.00	Mode 2.00	Mode 1	Mode 4.00	Mode 5.00	Mode 6.00	Mode 6.00	Mode 7.00	Mode 7.00	Mode 7.00	Mode 7.00	1 - Strong Effect	TR-3, TL-4, BR-1, BL-3, M-5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1 - Strong Effect
95	R.2.O.1.Y.4.G.3, B.5.1.4.V.7	Standard Deviation 1.82	Standard Dev 1.44	Standard Dev 2.0790	Standard Dev 1.2	Standard Dev 1.40	Standard Dev 1.20	Standard Dev 1.20	Standard Dev 1.20	Standard Dev 1.20	Standard Dev 1.20	Standard Dev 1.20	Standard Dev 1.20	1 - Strong Effect	TR-1, TL-2, BR-3, BL-4, M-5	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2 - Moderate Effect
96	R.5.O.4.Y.1.G.2, B.3.1.7.V.6	Sample Variance 3.33	Sample Var 2.08	Sample Var 4.31818	Sample Var 2.22	Sample Var 2.35	Sample Var 1.38	Sample Var 1.86	Sample Var 1.86	Sample Var 1.86	Sample Var 1.86	Sample Var 1.86	Sample Var 1.86	1 - Strong Effect	TR-4, TL-5, BR-1, BL-2, M-5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	1 - Strong Effect
97	R.1.O.2.Y.3.G.4, B.5.1.4.V.7	Kurtosis 0.02	Kurtosis 0.82	Kurtosis 1.12894	Kurtosis 0.15	Kurtosis 0.2	Kurtosis 2.47	Kurtosis 5.26	Kurtosis 5.26	Kurtosis 5.26	Kurtosis 5.26	Kurtosis 5.26	Kurtosis 5.26	1 - Strong Effect	TR-4, TL-3, BR-2, BL-1, M-5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	1 - Strong Effect
98	R.2.O.1.Y.3.G.4, B.5.1.4.V.7	Skewness 0.84	Skewness 1.00	Skewness 0.29064	Skewness 0.50	Skewness -0.46	Skewness -1.40	Skewness -2.12	Skewness -2.12	Skewness -2.12	Skewness -2.12	Skewness -2.12	Skewness -2.12	1 - Strong Effect	TR-3, TL-4, BR-1, BL-5, M-5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1 - Strong Effect
99	R.2.O.3.Y.1.G.4, B.5.1.4.V.7	Range 6.00	Range 6.00	Range 6.00	Range 4	Range 6.00	Range 6.00	Range 5.00	Range 6.00	1 - Strong Effect	TR-3, TL-4, BR-2, BL-3, M-5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1 - Strong Effect				
100	R.5.O.7.Y.4.G.2, B.3.1.4.V.1	Minimum 1.00	Minimum 1.00	Minimum 1.00	Minimum 1	Minimum 1.00	Minimum 1.00	Minimum 2.00	Minimum 1.00	3 - Low Effect	TR-4, TL-3, BR-1, BL-2, M-5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	1 - Strong Effect				
101	R.1.O.2.Y.3.G.4, B.5.1.4.V.7	Maximum 7.00	Maximum 7.00	Maximum 7.00	Maximum 4	Maximum 7.00	Maximum 7.00	Maximum 7.00	Maximum 7.00	Maximum 7.00	Maximum 7.00	Maximum 7.00	Maximum 7.00	1 - Strong Effect	TR-3, TL-1, BR-3, BL-2, M-5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2 - Moderate Effect
102	R.2.O.1.Y.5.G.4, B.3.1.4.V.7	Sum 100.00	Sum 99.00	Sum 110	Sum 101.00	Sum 136.00	Sum 189.00	Sum 208.00	Sum 208.00	Sum 208.00	Sum 208.00	Sum 208.00	Sum 208.00	1 - Strong Effect	TR-1, TL-2, BR-4, BL-3, M-5	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2 - Moderate Effect
103	R.5.O.4.Y.2.G.2, B.1.1.3.V.6	Count 34.00	Count 34.00	Count 34	Count 34.00	Count 34.00	Count 34.00	Count 34.00	Count 34.00	Count 34.00	Count 34.00	Count 34.00	Count 34.00	1 - Strong Effect	TR-3, TL-1, BR-2, BL-4, M-5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1 - Strong Effect
104	R.2.O.3.Y.7.G.1, B.4.1.5.V.4													1 - Strong Effect	TR-1, TL-3, BR-2, BL-4, M-5	1	3	3	3	3	3	3	3	3	3	3	3	3	3	2 - Moderate Effect
105	R.3.O.2.Y.1.G.4, B.5.1.4.V.7	Rank 1 (Best) 9.00	Rank 1 (Best) 4.00	Rank 1 (Best) 9	Rank 1 (Best) 7.00	Rank 1 (Best) 4.00	Rank 1 (Best) 6.00	Rank 1 (Best) 1.00	Rank 1 (Best) 2.00	1 - Strong Effect	TR-4, TL-3, BR-2, BL-4, M-5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	1 - Strong Effect				
106	R.1.O.3.Y.7.G.4, B.2.1.4.V.5	Rank 2 8.00	Rank 2 12.00	Rank 2 3	Rank 2 7.00	Rank 2 2.00	Rank 2 2.00	Rank 2 0.00	Rank 2 0.00	Rank 2 0.00	Rank 2 0.00	Rank 2 0.00	Rank 2 0.00	1 - Strong Effect	TR-2, TL-1, BR-3, BL-4, M-5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1 - Strong Effect
107	R.2.O.3.Y.5.G.6, B.1.1.7.V.4	Rank 3 5.00	Rank 3 9.00	Rank 3 4	Rank 3 6.00	Rank 3 6.00	Rank 3 1.00	Rank 3 1.00	Rank 3 1.00	Rank 3 1.00	Rank 3 1.00	Rank 3 1.00	Rank 3 1.00	2 - Moderate Effect	TR-3, TL-2, BR-3, BL-4, M-5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1 - Strong Effect
108	R.1.O.2.Y.3.G.4, B.5.1.4.V.7	Rank 4 6.00	Rank 4 4.00	Rank 4 5	Rank 4 11.00	Rank 4 4.00	Rank 4 3.00	Rank 4 1.00	Rank 4 1.00	Rank 4 1.00	Rank 4 1.00	Rank 4 1.00	Rank 4 1.00	1 - Strong Effect	TR-2, TL-5, BR-3, BL-4, M-1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1 - Strong Effect
109	R.3.O.2.Y.4.G.1, B.5.1.4.V.7	Rank 5 3.00	Rank 5 3.00	Rank 5 4	Rank 5 1.00	Rank 5 16.00	Rank 5 2.00	Rank 5 5.00	Rank 5 0.00	1 - Strong Effect	TR-2, TL-1, BR-3, BL-4, M-5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2 - Moderate Effect				
110	R.7.O.4.Y.2.G.1, B.4.1.5.V.4	Rank 6 0.00	Rank 6 1.00	Rank 6 3	Rank 6 1.00	Rank 6 0.00	Rank 6 22.00	Rank 6 7.00	Average Rank 2.15	Average Rank 2.74	Average Rank 2.53	Average Rank 3.65	Average Rank 3.94	1 - Strong Effect	TR-1, TL-3, BR-2, BL-4, M-5	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2 - Moderate Effect
111	R.4.O.2.Y.1.G.3, B.5.1.4.V.7	Rank 7 (Worst) 3.00	Rank 7 (Worst) 1.00	Rank 7 (Worst) 4	Rank 7 (Worst) 1.00	Rank 7 (Worst) 2.00	Rank 7 (Worst) 4.00	Rank 7 (Worst) 19.00	Rank 7 (Worst) 1.00	1 - Strong Effect	TR-1, TL-3, BR-2, BL-4, M-5	1	3	3	3	3	3	3	3	3	3	3	3	3	3	1 - Strong Effect				
112	R.2.O.3.Y.4.G.1, B.5.1.7.V.6	Average Rank 2.94	Average Rank 2.91	Average Rank 3.5	Average Rank 2.79	Average Rank 4.00	Average Rank 5.56	Average Rank 6.12	Average Rank 6.12	Average Rank 6.12	Average Rank 6.12	Average Rank 6.12	Average Rank 6.12	1 - Strong Effect	TR-1, TL-2, BR-4, BL-3, M-5	1	2	2	2	2	2	2	2	2	2	2	2	2	1 - Strong Effect	
113	R.4.O.2.Y.1.G.3, B.5.1.4.V.7													1 - Strong Effect	TR-3, TL-2, BR-3, BL-4, M-1	3	2	2	2	2	2	2	2	2	2	2	2	2	1 - Strong Effect	
114	R.1.O.1.Y.4.G.2, B.7.1.4.V.5													1 - Strong Effect	TR-3, TL-2, BR-4, BL-3, M-1	3	2	2	2	2	2	2	2	2	2	2	2	2	1 - Strong Effect	
115	R.1.O.2.Y.3.G.4, B.5.1.4.V.7													1 - Strong Effect	TR-2, TL-4, BR-1, BL-3, M-5	2	4	4	4	4	4	4	4	4	4	4	4	4	2 - Moderate Effect	
116	R.1.O.2.Y.4.G.3, B.4.1.7.V.6													2 - Moderate Effect	TR-2, TL-1, BR-3, BL-4, M-5	2	1	1	1	1	1	1	1	1	1	1	1	1	1 - Strong Effect	
117	R.4.O.4.Y.1.G.2, B.3.1.4.V.7													2 - Moderate Effect	TR-4, TL-3, BR-1, BL-2, M-5	4	3	3	3	3	3	3	3	3	3	3	3	3	1 - Strong Effect	
118	R.3.O.2.Y.1.G.4, B.5.1.4.V.7													1 - Strong Effect	TR-3, TL-4, BR-1, BL-2, M-5	3	4	4	4	4	4	4	4	4	4	4	4	4	2 - Moderate Effect	
119	R.4.O.5.Y.4.G.3, B.1.1.2.V.7													1 - Strong Effect	TR-3, TL-5, BR-1, BL-4, M-2	3	5	5	5	5	5	5	5	5	5	5	5	5	1 - Strong Effect	
120	R.2.O.4.Y.4.G.3, B.1.1.4.V.7													1 - Strong Effect	TR-1, TL-2, BR-3, BL-4, M-5	1	2	2	2	2	2	2	2	2	2	2	2	2	1 - Strong Effect	
121	R.1.O.2.Y.3.G.4, B.5.1.4.V.7													1 - Strong Effect	TR-3, TL-3, BR-1, BL-4, M-5	2	3	3	3	3	3	3	3	3	3	3	3	3	2 - Moderate Effect	
122	R.3.O.1.Y.2.G.5, B.4.1.4.V.7													1 - Strong Effect	TR-1, TL-3, BR-2, BL-4, M-5	1	3	3	3	3	3	3	3	3	3	3	3	3	1 - Strong Effect	
123	R.3.O.4.Y.2.G.1, B.7.1.4.V.5													1 - Strong Effect	TR-1, TL-2, BR-3, BL-4, M-5	1	2	2	2	2	2	2	2	2	2	2	2	2	2 - Moderate Effect	
124	R.4.O.3.Y.1.G.2, B.5.1.4.V.7													1 - Strong Effect	TR-1, TL-3, BR-2, BL-4, M-5	1	3	3	3	3	3	3	3	3	3	3	3	3	2 - Moderate Effect	

