The effect of heads-up-display (HUD) goggles on skiing and snowboarding speeds

by
Jonathan Matthew Frederick Garner
B.Sc., Leeds Metropolitan University, 1999

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Approval

Name: Jonathan Matthew Frederick Garner
Degree: Master of Resource Management
Report No. 650
Title: The effect of heads-up-display (HUD) goggles on skiing and snowboarding speeds
Examing Committee: Chair: Sergio Fernandez Lozada
Master of Resource Management Ph.D Candidate
Pascal Haegeli
Senior Supervisor
Assistant Professor

Alison Gill
Co-Supervisor
Professor

Date Defended/Approved: June 27, 2016
Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

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Abstract

This study empirically explores whether the use of heads-up-display (HUD) goggles increases the risk in ski areas by increasing skiing and snowboarding speeds. Twenty-seven skiers and snowboarders participated in a repeated measures experiment that included a control session without the HUD goggle and three sessions with the HUD goggle under a variety of conditions. The skiing behaviour of each participant was monitored using a Global Positioning System (GPS) tracker. The runs of the ski area were divided into 51 homogeneous run sections and speed quantiles (median to maximum in 5 percentage point intervals) were calculated for each individual pass through these run sections (n=4,451). A mixed-effects model was then applied to examine the effect of HUD goggles on skiing speeds for each quantile in combination with various personal (e.g., skiing ability) and external factors (e.g., terrain). Among the variables tested, ability level had the strongest positive effect on skiing speeds, while terrain characteristics including steep gradients, ungroomed runs, and treed areas, were all associated with slower skiing speeds. No overall long-term effect of HUD goggle use on skiing speeds was found, but advanced/expert skiers did appear to benchmark ‘personal best’ speeds during first HUD use – particularly on long straight run sections – before returning to slower speeds during subsequent HUD use. Whereas no significant HUD effect was observed among beginners/intermediates, skiing speeds were significantly faster among beginners/intermediates listening to music during the sessions. The potential for distraction as a result of HUD use still requires investigation.

Keywords: Snowsports; Wearable Technology; Music; Safety; Risk; Alpine Resort Management
Dedication

To my wife Ju for making it all possible, and my sons Patrick, Felipe, and Rafael for making it all worth it.

Finally, it’s time to go skiing.
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I also give thanks to Alison Gill, my Co-Supervisor for stepping in at the last-minute so supportively, and for introducing me to the Grand Tour. GEOG 327 was a blast.

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Special thanks also go to the following: Michelle Jones for your extremely generous help with coding, Stephen Caine - SFU's incredibly helpful risk manager – for the rock solid waiver, Lawrence Lee for being the kindest and best IT person I have ever met, and Iris Schischmanow for patiently explaining how things work from the first day to the last.

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Declaration of Co-Authorship and Previous Publication

I. Co-Authorship Declaration

I hereby declare that this thesis incorporates material that is result of joint research undertaken in collaboration with Dr. Pascal Haegeli and Dr. Wolfgang Haider. My main contribution included the background literature review, participant recruitment, data collection, descriptive and univariate analysis. My collaboration with Dr. Pascal Haegeli included formulation of the research questions and hypothesis, experimental design, survey design, development of the method for pre-processing personal information and GPS data, statistical design, and interpretation of the results. Dr. Pascal Haegeli’s additional contributions included characterising terrain, developing the multivariate regression model, and illustrating the results. My collaboration with Dr. Wolfgang Haider included formulating the experimental design, designing the online survey, and overall guidance on linking this research to related topics in outdoor recreation and tourism. I certify that I have properly acknowledged the contribution of other researchers to my thesis, and have obtained permission from each to include their contributions in my thesis. With the above qualification, this thesis, and the research to which it refers, is the product of my own work.

II. Declaration of Previous Publication

This thesis includes materials from an original paper previously published in a peer-reviewed journal.


This thesis expands on the above journal paper by providing additional background literature, further interpretation of the results in the discussion, a new section on potential opportunities, further considerations for future research, and an appendix.
Chapter 1.

Introduction

Resort skiing and snowboarding (herein referred to as skiing) takes place at about 2,000 ski areas around the world attracting approximately 400 million visits annually (Vanat, 2014). Participants choose resorts based on factors such as variety of runs, snow conditions, and value for money (Carmichael, 1996), and take part for a mixture of reasons including personal achievement, social reasons, enjoyment of nature, escape, and thrills (Hudson, 2000).

Recent technology advances have created a multitude of new devices designed to augment the skiing experience, and considerable growth in the use of smart wearable devices is expected (Juniper Research, 2014). Similar to cycling, where the use of trip computers is well established (Fleishman, 2000), many skiers today use smartphone applications or smartwatches to record speed, distance, and vertical (Kirby, 2014), ski helmets that play music through built-in head-phones, and wearable video cameras mounted to various ski equipment (Pullen, 2015). At the cutting edge of this trend is a heads-up-display (HUD) goggle (Figure 1.), with a small screen showing current and maximum speed (km/h), distance (km), vertical descent (m), altitude (m), and an interactive resort map. The benefits of HUD goggles include real-time access to dashboard metrics, the location of trails, lifts, and resort facilities, buddy tracking, and synchronization with smartphones to access music, text message, and call functions. These benefits can be extended to include information such as lift wait times and slope congestion to help users avoid known satisfaction issues such as long lift lines (Perdue, 2002) and overcrowded slopes (Clydesdale, 2007). In 2015, for example, Vail Resorts introduced the ability to view up-to-the-minute lift-line wait times via their dedicated resort smartphone application (Vail Resorts, 2015).
Figure 1. Recon Instruments MOD Live heads-up display showing current and maximum skiing speed.

Skiing is an inherently risky activity, with an overall injury rate of approximately 2.5 injuries per thousand skier visits (Johnson, Ettlinger, & Shealy, 1997). While higher injury rates have been associated with male gender (Wasden, McIntosh, Keith, & McCowan, 2009), younger age (Kim, Endres, Johnson, Ettlinger, & Shealy, 2012), lower ability (Goulet, Hagel, Hamel, & Légaré, 2010), ill-adjusted equipment (Johnson, Ettlinger, & Shealy, 2009) and unanticipated collisions with trees, rocks, or other skiers (Zuckerman, 2007), excessive speed is the dominant cause of injury (Macnab, Cadman, & Greenlaw, 1998). In extreme cases, excessive speed has also been identified as a contributing factor in fatalities at ski areas (Shealy & Thomas, 1996).

Mobile and wearable technology use while skiing is a potential new source of risk. Media reports associate smartphone application use with excessive speed as a result of access to real-time metrics (Kirby, 2014) and link high tech displays in sports eyewear with distraction (Richtel, 2013). Research by Dickson et al. (2012) also suggests that HUD use should be studied in relation to influencing higher risk-taking behaviours such as excessive speed, while Langran (2013) warns that HUD goggle users should take care to avoid becoming distracted by the screen. To maintain the safety of all resort users, ski area managers need to know if HUD goggles present an
increased threat of injury to the wearer – or to other slope users nearby – and if so, how to potentially mitigate such risks.

1.1. Study purpose

The purpose of this study is to address this knowledge gap by empirically exploring the effect of HUD use on skiing speed as a function of personal (e.g., age, ability, motivation, use of other technology) and external (e.g., weather, terrain) factors. We hypothesize that HUD use affects maximum skiing speeds the most and that the effect is weaker at lower speed quantiles (e.g., median speed). To test this, we specifically examine the following research questions:

(1) Does HUD goggle use affect skiing speeds?

(2) How is the effect of HUD goggles on skiing speeds moderated by personal factors (e.g., gender, skiing ability) and external factors (e.g., terrain characteristics, weather conditions)?

The report is structured as follows: A review of existing literature related to ski resort management, skiing and technology, risk-taking behaviour, injuries and prevention, and skiing speeds is followed by a description of the data collection and analysis. The results of a mixed-effects model and model speed estimates are presented, and then discussed in the context of related literature. Finally, we discuss implications for alpine resort managers, potential opportunities, and make recommendations for future research.
Chapter 2.

Background

2.1. Ski resort management

Alpine resort managers oversee the safety of visitors and the protection of natural resources within the defined physical boundary of the resort according to a specific regulatory framework. For example, at Cypress Mountain - the field site for this study (see section 3.2 for detailed description), skiing takes place in a controlled recreation area surrounded by provincial parkland under the governance of a park master plan that allows for intensive recreation zones (BC Parks, 1997). In addition, managers at the resort must comply with legislation including the Federal Fisheries Act, Provincial Water Act, Park Act (Whitford, 2005), the Park Act Regulations and a specific Park Use Permit (#1506) (BC Parks, 1997).

To provide a safe and enjoyable experience for visitors, managers must carefully manage a range of physical factors (e.g. terrain) and human factors (e.g. skier behaviour). Terrain use is planned via calculating 'skier carrying capacity', which is defined as the maximum number of skiers that the lifts and slopes can comfortably support at any one time without overcrowding (Whistler Blackcomb, 2010), and 'lift capacity', which represents the maximum number of skiers the lift system can support per hour (Clydesdale, 2007). In addition, benchmarks for skier density in different locations within a resort are organized by skiing ability and range from 10-15 skiers per acre for beginners down to 3-5 skiers per acre for experts (Clydesdale, 2007).

To understand and manage skiers effectively, managers must monitor their behaviour. Canadian Ski Patrol staff are tasked with visually observing the skiing behaviour of the general public while carrying out other patrol responsibilities (Canadian
Ski Patrol, 2016). In comparison, more rigorous methodologies for visitor monitoring are common in other fields of outdoor recreation and tourism. For example, periodic surveys are used to determine acceptable crowding norms for trail walking (Arnberger & Haider, 2007) and summer hiking (Needham, Rollins, & Wood, 2004), while the efficacy of automatic counter and visual recording technologies in parks has been established for some time (Cessford & Muhar, 2003).

More recently, outdoor recreation and conservation managers have started to use precise spatial information via Global Positioning Satellite (GPS) and Geographic Information Systems (GIS) to record, analyze and visualize detailed visitor behaviour patterns (Orellana, Bregt, Ligtenberg, & Wachowicz, 2012; Taczanowska, Muhar, & Brandenburg, 2008; D’Antonio et al., 2010; Leung, Walden-Schriener, & Miller, 2012). The benefit of using GPS and GIS techniques is the extremely high resolution of data (Taczanowska et al., 2008), providing much more precise, accurate and reliable information on visitor behaviour (Hallo et al., 2012; D’Antonio et al., 2010) than the coarse spatial scale of data generated by surveys, interviews and counters (Wolf, Stricker, & Hagenloh, 2012).

Ski resort managers would benefit from more comprehensive information about how far alpine skiers travel, how fast they travel, where they congregate, what demands their activities place on resort infrastructure, and what impact they have on each other. However, so far applications of GPS and GIS methods in ski area management appear to be rare. GPS trackers have been used to analyze the disturbance effect of backcountry skiing in protected areas home to endangered species (Rupf et al., 2011), but little research about skiing behaviour within resort boundaries exists. A notable exception is Dickson, Terwiel, Waddington, and Trathen (2011), who describe for how long, over what distance, and at what speeds alpine skiers travel during a typical day of skiing. This and other studies of skiing speed are discussed in more detail in section 2.5.

Injuries in alpine skiing are associated with a number of factors including excessive speed (Shealy & Thomas, 1996; Zuckerman, 2007; see section 2.4 for further details). Common management techniques to control skier speed include ski area codes of conduct, speed warning signs e.g. “slow zone”, speed patrollers, mesh fences
In addition, ski area managers use their understanding of local terrain. For example, at Whistler Blackcomb resort, managers note that steep, ungroomed slopes dictate a need for controlled, short radius turns and conclude that under these conditions, expert skiers travel at slower speeds and require less space for safe skiing (Whistler Blackcomb, 2010). Nevertheless, reckless high speed skiing – particularly in slow zones – remains an issue and resort managers impose penalties including warnings by Ski Patrol staff and removal of visitors’ lift passes in some cases (Brooke, 1999).

2.2. Technology and skiing

There are a number of technologies skiers can choose from to augment their experience. A popular choice is listening to music via headphones or an audio-helmet. Ruedl et al., (2012) show that using an audio helmet has no significant impact on skier reaction times. However, listening to music has been associated with fewer – but more serious – injuries among snowboarders in terrain parks (Russell et al., 2014). Listening to music has also been examined in other fields of outdoor recreation. Music has been shown to have almost no impact on the speed of cyclists in a field setting (de Waard, Schepers, Ormel, & Brookhuis, 2010), but Atkinson, Wilson, and Eubank (2004) found that music resulted in increased cycling speed on an ergometer. A positive effect of listening to music on speed has also been established for runners (Edworthy & Waring, 2006).

Another set of technologies available to skiers today take advantage of the functions provided by modern smartphones. Launched in 2007, the iPhone featured built-in GPS and an accelerometer giving it the potential to accurately record movement (Greene, 2007). The rapid consumer uptake in smartphones – 66% of Canadians now own one (CRTC, 2015) – means that many skiers and snowboarders use smartphone applications or smartwatches to record speed, distance, and vertical (Kirby, 2014), and connect additional accessory devices including wearable video cameras and cord-free headphones (Pullen, 2015).
At the cutting edge of technology available to skiers is the HUD goggle. To our knowledge, there is no existing research that has examined the effect of HUD use in outdoor recreation or skiing in general and with respect to safety in particular. However, substantial research exists on the effect of HUD use on driving behaviour. Tonnis, Lange, and Klinker (2007), for example, show that users drive faster with HUD assistance than without it, and Liu and Wen (2004) indicate that speed control (variations in driving speed) is improved during HUD use. Reaction time to speed limit warnings (Liu, 2003) and emergency information processing is also faster during HUD use (Liu & Wen, 2004), but brake response times increase by up to 30% (Wolffsohn & McBrien, 1998). Liu (2003) also notes a “novelty effect” associated with HUD use, suggesting that the effects change over time as users become familiar with the technology.

2.3. Risk-taking behaviour

Numerous personal factors including gender, age, and ability are known to be associated with higher skiing speeds and risk-taking behaviour in general. Males typically ski faster than females (Shealy, Ettlinger, & Johnson, 2005), and report significantly higher rates of risky skiing behaviour (Ruedl et al., 2010; Ruedl, Abart, Ledochowski, Burtscher, & Kopp, 2012). Younger skiers (Ruedl et al., 2010) – specifically those under 25 years of age (Ruedl, et al., 2012) – are also more likely to take risks, while skiers of higher ability levels including ‘advanced’ (Ruedl et al., 2010) also report greater risk-taking behaviour. Lastly, higher speed itself is associated with risk taking. For example, self-identified risk-takers are shown to ski at higher speeds compared to more cautious skiers (Ruedl et al., 2010).

In addition to demographics, the personality trait Sensation Seeking (SS) is often used to understand skier behaviour. Sensation seeking is defined as “the need for varied, novel and complex sensations and experiences and the willingness to take physical and social risks for the sake of such experience.” (Zuckerman, 1979 p.10). The sensation seeking scale is itself divided into four separate sub-scales: (1) Thrill and Adventure Seeking - the desire to engage in risky and adventurous activities and sports providing unusual sensations; (2) Experience Seeking - the search for stimulation
through the mind and the senses, e.g. through music, art, travelling and drugs; (3) Disinhibition - seeking of sensation expressed through drinking, partying, gambling and sexual activity; and (4) Boredom Susceptibility - an aversion to repetitive experiences and a restlessness or boredom in such circumstances (Zuckerman, 1983). Various studies have revealed an association between risky skiing behaviour and sensation seeking. For example, Ruedl, et al., (2012) and Haegeli, Gunn, and Haider (2012) show that higher scores on Zuckerman’s sensation seeking scale are associated with risky skiing behaviour among amateur skiers. Gracz, Elegańczyk-Kot, and Walczak (2008) show that ski racers score between high and very high on the Thrill and Adventure Seeking (TAS) sub-scale. More recently, Thomson, Morton, Carlson, and Rupert (2012) developed a Contextual Sensation Seeking Questionnaire (CSSQ) to more specifically measure sensation seeking among skiers and snowboarders, and linked high CSSQ scores with the presence of a specific genetic variant (Thomson et al., 2013).

2.4. Injuries and prevention

The injury rate in alpine skiing is approximately 2.5 injuries per thousand skier visits, and while trends indicate that some injuries such as lower leg injuries, lacerations, and thumb injuries are in decline, serious knee injuries and clavicle fractures continue to increase (Johnson et al., 1997). Among snowboarders specifically, research finds that wrist injuries, shoulder soft tissue injuries, ankle injuries, concussions, and clavicle fractures are common, while skiers tend to sustain more anterior cruciate ligament sprains, medial collateral ligament sprains of the knee, lateral collateral ligament sprains of the knee, lower extremity contusions, and tibia fractures (Kim et al., 2012).

Demographic profiling of injured skiers finds males (70% for skiers, 87% for snowboarders) represent the majority of cases requiring hospital treatment (Wasden et al., 2009). Younger age is also associated with injury risk, with the average age of an injured snowboarder (20 years old) being lower than the average injured skier (30 years old) (Kim et al., 2012). Aside demographics, the main risk factors associated with alpine skiing include low skill and ill-adjusted equipment (Goulet, Régnier, Grimard, Valois, & Villeneuve, 1999; Johnson et al., 2009), new skiing equipment (Hasler et al., 2009),
Injury prevention in skiing focuses mainly on helmet use. A number of studies show that wearing a helmet is effective at preventing head injuries in skiers and snowboarders (Machold et al., 2000; Macnab, Smith, Gagnon, & Macnab, 2002; Russell, Christie, & Hagel, 2010; Sulheim, Ekeland, & Bahr, 2004), however controversy exists over whether or not wearing protective equipment also increases risk-taking behaviour. The risk compensation theory suggests that individuals may take greater risks as a result of feeling protected by helmet use (Thompson, Thompson, & Rivara, 2001), and is supported by survey findings that link ski helmet use to higher risk index scores (Ružić & Tudor, 2011). However, this theory is rejected by studies that compare the relationship between risk-taking behaviour and helmet use with other personal factors (Scott et al., 2007; Hagel, Pless, Goulet, Platt, & Robitaille, 2005). For example, Ruedl et al., (2010) show that risk-taking behaviour while skiing is associated with younger age, higher skiing ability, male sex, higher average speeds, and not helmet use (Ruedl et al., 2010). In addition, studies where helmet use does predict risky behaviour find it a weaker predictor than sex, ability, and sensation seeking (Thomson & Carlson, 2015).

Despite increased helmet usage in Western Canada over recent seasons, the proportion of all reported snowsports injuries that are head injuries is not decreasing (Dickson, Trathen, Terweil, Waddington, & Adams, 2015). A possible reason for this may be the fact that average skiing speeds now far exceed 23 km/h, the speed used in testing protocols for ski helmets (Dickson, Trathen, & Waddington, 2015). Nevertheless, researchers still recommend helmet use, concluding that any increased risk likely does not offset the considerable benefits of wearing protective gear (Thomson & Carlson, 2015), and that helmet use still reduces the risk of head injuries among skiers and snowboarders (Ruedl et al., 2010).

### 2.5. Skiing speeds

A considerable amount of research has been conducted on skiing speeds in relation to risk-taking behaviour in skiing. Recreational skiing speeds have increased...
dramatically in recent decades. Average speeds attained while skiing have increased from an estimated 34.7 km/h in the late 1970’s to 43.0 km/h by 2005 (Shealy et al., 2005), with the increase attributed to grooming practices, slope design, and boot and ski technology. A recent study by Ruedl et al. (2013) revealed mean speeds of 48.2 km/h on slopes of medium difficulty, but Williams et al. (2007) show that skiers navigating non-traditional terrain such as gladed areas and freestyle parks still travel at much lower speeds of below 24.1 km/h. In terms of maximum speeds, research by Dickson et al. (2011) observes a mean maximum skiing speed of 62.0 km/h, and highlights that top maximum speeds now exceed 100 km/h.

Whether or not skiers are aware of the speed at which they travel, and how this compares to how fast they think they should travel has also been investigated. Overall, skiers tend to underestimate their speed by an average of 12 km/h (Dickson et al., 2012). The ability of skiers to estimate their speed tends to decrease the faster they go (Shealy et al., 2005), and speeds often exceed their own concept of what is a ‘safe speed’. For example, a recent study shows participant’s actual speeds through a slow zone are on average 23.5 km/h faster than they believe to be safe (Dickson et al., 2012). Whether or not greater awareness of speed, through the use of HUD goggles or other devices, would influence skiers to speed up for greater thrills, or slow down to increase safety, is unknown.
Chapter 3.

Method

3.1. Experimental design

This study used GPS tracking methods to empirically record skiing speeds both before and during HUD goggle use. We took a repeated measures approach, collecting multiple samples from each participant and examining unique passes through homogeneous ski run sections to understand the effect of HUD use on speed at the level of the individual, rather than the sample overall. A repeated measures design is the only method for obtaining information about individual patterns of change over time, and allows subjects to serve as their own controls (i.e., removing between-subject sources of variability) (Davis, 2002).

In this study, each of the participants was asked to complete four approximately 2-hour skiing sessions. During the first session, participants carried a small passive GPS tracker with no display while skiing freely. The GPS records from this initial session served as the control (CTRL) for the analysis. Once participants had completed their CTRL session, we gave them instructions on how to use the HUD goggle and asked them to take part in three additional, approximately 2-hour test sessions (HUD1, HUD2, HUD3) over the next four weeks. In these sessions, participants used the HUD goggle with no further instructions and carried the GPS tracker as before to maintain a consistent record of skiing speeds. The multiple HUD test sessions allows for the examination of the temporal evolution of the HUD effect on skiing speeds and therefore the separation of ‘novelty’ or ‘learning’ effects associated with first-time HUD goggle use from persistent long-term effects. The panel structure of our dataset was imperfectly crossed between participants and days, and days and run sections (Figure 2.).
Figure 2. Crossed panel structure of data shows participant and day imperfectly crossed, and day and run section imperfectly crossed.

3.2. Study area

The study area for this research was Cypress Mountain ski area, situated in West Vancouver, British Columbia, Canada, a 30-minute journey from downtown Vancouver and easily accessed from the surrounding Metro Vancouver region (population ~2.3 million). The ski area offers a total of 240 ha of skiable terrain, providing a variety of groomed green, blue, and black runs (Figure 3.), four freestyle areas, and some off-piste terrain between runs. The average snowfall per season is 1,000 centimetres (Cypress Mountain, 2015). Because most visitors to Cypress Mountain are repeat day visitors throughout the season, rather than one-week visitors (more common at destination resorts), it is particularly well suited to examine behaviour change over time.
Figure 3. Satellite photograph of Cypress Mountain showing run sections colour coded according to their rating (green, blue and black) and chairlifts (red). Cypress Mountain is located at longitude and latitude 49°23′46.04″N and 123°12′15.60″W (Background image copyright by Province of British Columbia and Google).

3.3. Equipment

The HUD goggles used in this study were Recon Instruments MOD Live devices (Figure 1.). During the experiment, the screen was configured to display speed, distance
and altitude. Separate custom designed, passive GPS tracking devices without a display were used to record location information with a horizontal positional accuracy of 4 m (Rupf et al., 2011). During the experiment latitude and longitude were recorded at 1 second intervals. After each session, data from the GPS trackers were downloaded and stored in a text file in Comma Separated Values (CSV) format.

3.4. Recruitment and participant surveys

A convenience sample of skiers was recruited over four weeks prior to study commencement via the Cypress Mountain website and by maintaining a promotional stand in the main lodge at the base of the ski area (See Appendix A). Interested participants were informed that the broad purpose of the study was to analyze their skiing behaviour with and without a HUD goggle. Prior to engaging in any recorded skiing, each participant was asked to sign the study consent and liability release forms (minimum age requirement – 19 years old), and to complete a brief online background survey (see Appendix B) to capture demographic information, self-reported ability level, typical technology use, and familiarity with the resort. The online survey profiled participants using the Brief Sensation Seeking Scale (BSSS) (Hoyle, Stephenson, Palmgreen, Lorch, & Donohew, 2002), the CSSQ (Thomson et al. 2012), and recorded their motivations for visiting the Cypress Mountain ski area using the Recreation Experience Preferences (REP) scale (Manfredo, Driver, & Tarrant, 1996).

After each session, participants were asked to complete a brief online follow-up survey (see Appendix B) to collect information about their skiing experience. Questions included type of activity (skiing or snowboarding), motivation for their visit, technology use during the session, speed estimates, and satisfaction with different aspects of their experience.

Participation in the study decreased from the control session (CTRL: n=56), to the subsequent HUD sessions (HUD1: n=51; HUD2: n=36; HUD3: n=27), giving a final completion rate of 48%. We restricted the analysis to participants that completed all four sessions in order to reduce unnecessary variability in the dataset. Since information on the number of website views during our recruitment period is not available and we did
not record the number of individuals passing by the promotional stand, it is not possible to provide a response rate for the study.

3.5. Environmental conditions and terrain characterization

Weather and snow conditions with the potential to effect skiing speeds were recorded daily from the Cypress Mountain website. Recorded parameters included precipitation type, visibility, and amount of new snow in the last 24 hours.

To integrate terrain characteristics into the analysis, the skiing terrain of Cypress Mountain was divided into homogeneous ski run sections. Information sources for this terrain characterization included the ski resort trail map, a digital elevation model obtained from Natural Resources Canada (http://geogratis.gc.ca/), and local terrain knowledge of the research team. In addition, the GPS data collected in this study were used to identify typical ski routes in the resort. This terrain analysis identified 51 homogeneous run sections using seven relevant terrain attributes: difficulty rating, typical steepness, grooming, proximity to chairlift station, typical run width, whether the run is merging with another ski run, and whether the section consists of a long straight stretch (Table 1). It is important to note that the terrain classification for this study was based on a qualitative, overall inspection of the terrain and not a precise geospatial classification algorithm. We believe that the more descriptive approach suited the analysis better as it was able to capture the character of the skiing terrain more comprehensively.
Table 1 - Attributes and levels used for run section characterization

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating</td>
<td>Green</td>
</tr>
<tr>
<td></td>
<td>Blue</td>
</tr>
<tr>
<td></td>
<td>Black</td>
</tr>
<tr>
<td>Steepness</td>
<td>Flat &lt;10</td>
</tr>
<tr>
<td></td>
<td>Moderate 10-20</td>
</tr>
<tr>
<td></td>
<td>Steep 20-30</td>
</tr>
<tr>
<td></td>
<td>Steepest &gt;30</td>
</tr>
<tr>
<td>Groomed</td>
<td>Regularly</td>
</tr>
<tr>
<td></td>
<td>Not regularly</td>
</tr>
<tr>
<td>Near lift</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Width</td>
<td>Treed</td>
</tr>
<tr>
<td></td>
<td>Narrow</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Wide</td>
</tr>
<tr>
<td>Merging</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Minor</td>
</tr>
<tr>
<td></td>
<td>Major</td>
</tr>
<tr>
<td>Long &amp; straight</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>

3.6. Pre-processing of personal background information

All of the data pre-processing and the entire statistical analysis for this study was conducted in R (R Core Team, 2014). Responses to BSSS, CSSQ and REP questions in the background survey needed to be pre-processed before being included in the statistical analysis of skiing speed. From the individual responses to the eight BSSS questions, average scores for overall SS as well as its four subscales were calculated for each participant. The responses to the ten CSSQ questions were simply averaged to provide an overall score. The REP scale items were pre-processed using a principal component analysis (‘prcomp’ function in R). Only principal components with eigenvalues $> 1.0$ were retained for the statistical analysis of skiing speed. Principal
components used in analysis were interpreted based on their correlations with the original survey questions.

### 3.7. Pre-processing of GPS data

An algorithm was developed in R to pre-process the raw GPS tracks of each participant and extract the necessary information for the statistical analysis. The pre-processing included deleting observations from irrelevant locations, assessing the quality of GPS signal and eliminating low quality observations, identifying passes through homogeneous run sections and calculating speed statistics to capture the characteristics of the observed skiing speeds. The developed algorithm relies on the functionality of the following R packages: chron (James & Hornik, 2014); rgdal (Bivand, Keitt, & Rowlingson, 2014); sp (Bivand, Pebesma, & Gómez-Rubio, 2013); and geosphere (Hijmans, 2014).

GPS points located outside the ski area, within the guest lodge or in parking lot areas were immediately deleted from the dataset. Any points with a Dilution of Precision (DOP) value > 6 were also deleted to ensure a high quality of GPS signal (see Wing, Eklund, & Kellogg 2005). To smooth the GPS track before calculating distance and speed values for each observation, we applied 5-second running means to the observed longitude and latitude values.

To separate ski runs from ascents, GPS observations within 10 m of a chairlift were identified as lift journeys. In addition, observations within a 40 m radius of a lift station were also considered to be part of the lift journey since these locations are typically associated with lining up, loading and unloading, adjusting equipment or waiting for partners. Continuous GPS observations between lift journeys were identified as ski run tracks.

GPS units occasionally recorded obviously erroneous location information (e.g., uphill tracks deviating from chairlift courses, random skiing in dense forest away from ski runs). To ensure that the analysis dataset was of high quality, the algorithm assessed positional accuracy of each lift journey by comparing GPS observations to the known
locations of chairlift courses and stations. Ski run tracks were only included in the analysis dataset if a) they started from a known chairlift station, b) were within known ski run terrain, and c) more than 75% of the GPS observations on the last 250 m of the preceding chairlift journey were within 10 m of the chairlift course.

Ski run tracks of sufficient quality were then divided into individual run section passes by comparing their locations to the 51 previously identified homogeneous ski run sections (see Section 3.5.). Passes with exceptionally low numbers of observations (threshold run section dependent) were eliminated because they did not represent complete passes of the run section (e.g., a skier only briefly entering a run section while skiing down an adjacent run). To ensure that the calculated speed statistics only represented skiing behaviour, observations with speeds < 5 km/h (walking pace or slower) or > 120 km/h (unrealistic amateur skiing speeds) were eliminated prior to these computations. To summarize the characteristics of the skiing speeds of each participant during each unique run section pass, speed quantiles were calculated from 50% (median speed) to 100% (maximum speed) at 5 percentage point intervals. These summary statistics comprehensively capture the skiing speed behaviour of each individual participant on each of their run section passes (see Figure 4.).
Figure 4. Example of individual pass through a homogeneous run section (Panel A: map view; Panel B: time series; Panel C: speed distribution) with speed observations coloured according to their quantiles (50–75%: yellow, 75–90%: orange, 90–95%: red, 95%: black). Red dashed lines indicate 50%, 75%, 90% and 95% quantiles.
3.8. Statistical analysis

A univariate analysis was first conducted to explore relationships between variables that might inform a more in-depth analysis of speed behaviour. Given our sample violates some assumptions of parametric statistical tests – in particular our sample was not random and speed values did not resemble normal distribution – we used non-parametric tests that do not rely on these assumptions (Hollander & Wolfe, 1999). The Wilcoxon rank-sum test (also known as the Mann Whitney U Test) was used to compare categorical and numeric variables between two groups, the Kruskal-Wallis test for comparing categorical and numeric variables among three or more groups, the Pearson’s Chi-square test for comparing categorical data, and the Spearman rank-order correlation to test the independence of two numeric variables.

Since a range of factors influence skiing speed simultaneously, a multivariate approach was required to properly isolate the effect of individual factors. A traditional multiple regression model is sufficient to investigate a number of predictor variables simultaneously, but assumes that observations are independent from each other (Kutner, Nachtsheim, Neter, & Li, 2005). However, in a repeated measures design, it is likely that correlations exist among observations from the same individual (Jiang, 2007). To properly account for these types of correlations within our dataset, we used a linear mixed-effects model (Gałecki & Burzykowski, 2013), which also allowed us to account for random effects associated with participant, day, and run section, and to effectively partition overall variation of our dependent variable into components corresponding to different levels of data (Gałecki & Burzykowski, 2013) – directly addressing the hierarchal structure of the dataset illustrated in Figure 2.

To explore the effect of HUD goggles on different aspects of the speed distribution (e.g., effect on median speed, effect on maximum speed) in each run section pass, we followed the concept of quantile regression (Koenker & Bassett, 1978). Whereas typical regression analyses examine relationships between the mean of the dependent variable and the independent variable, quantile regression is a method for estimating functional relationships between variables for all proportion of a probability distribution (Cade & Noon, 2003). However, since we were interested in the effect on the
speed quantiles in individual run section passes and not on quantiles of all speed observations combined, we needed to derive models for each quantile separately.

Separate mixed-effects models for different speed quantiles were developed in R using the lme4 (Bates, Maechler, Bolker, & Walker, 2014) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2014) packages. For the analysis, speed quantile values were transformed to the power of 1/3 (determined by the Box-Cox method; Box & Cox, 1964). While this transformation makes the resulting regression coefficients more difficult to interpret, it resulted in a more favourable distribution of the residuals. All categorical and ordinal attributes were dummy coded with a beginner/intermediate participant skiing during good visibility on a flat to moderately steep, open run section that is typically groomed as the base level. The speed quantile models were developed by first calculating a base model with three random intercepts (participant, run section, day). Fixed main effects for run section characteristics, weather and snow observations, and participant characteristics were then added sequentially before any interaction effects were explored. After that, any HUD related main and interaction effects were included in the model. Attributes were only included in the model if their main effect or any of their interaction effects were statistically significant at the 5% level (i.e., $p < 0.05$). We used the likelihood ratio test to examine the effect of additional attributes on model performance, and used the Akaike Information Criterium (AIC; Akaike, 1974), Bayesian Information Criterium (BIC; Schwarz, 1978) and interpretability to guide model selection.

The first model was derived using the 95% speed quantile as we expected HUD goggles to have a stronger effect on top skiing speeds. The 95% quantile represents top speeds without being overly affected by outliers. We then used the 50% speed quantile to develop a second model to explore the effect of HUD goggles on medium speeds. All of the main and interaction effects that emerged as significant from either of these two models were included in the final model specification, which we then applied to all speed quantiles of interest (50% to 100%, in 5 percentage point intervals).
3.9. Illustration of results

It is difficult to directly visualize the combined effect of all HUD related main and interaction effects and the $^{1/3}$ transformation of the speed quantile values makes the interpretation of the regression coefficients particularly challenging. To facilitate the interpretation of the results of the regression analysis, we calculated speed point estimates for specific scenarios (e.g., beginner/intermediate vs. advanced/expert skiers on long, straight run sections) for all stages of the experiment (CTRL, HUD1, HUD2, HUD3). While the point estimates were calculated directly based on the parameter estimates from the regression models, the associated 95% prediction intervals were calculated by simulation relative to the CTRL stage for each group (e.g., beginner/intermediate vs. advanced/expert skiers). Whereas the regression coefficients of parameters that did not vary within the scenario of interest (e.g., ability, visibility) were kept constant (i.e., we used the parameter estimate directly), parameters varying within the scenario (e.g., effect of HUD, learning effect) were included in the calculation of the 95% prediction interval by sampling a set of 10,000 regression coefficients from the parameter distributions represented by the results of the regression (normal distribution with parameter estimate as expected value and standard error as standard deviation). The sampled regression coefficients were then used to compute 10,000 speed estimates and estimate the 95% prediction intervals for each stage of the experiment and grouping.
Chapter 4.

Results

4.1. Study sample

The final sample of participants (n=27) was predominantly male (89%) with a median age of 33, snowboarders (63%), of intermediate (41%) or advanced (37%) ability, who typically listen to music (56%) or use a wearable camera (26%) while skiing. Their median BSSS score was 3.5/5, and median CSSQ score was 3.3/5. We did not find a significant correlation between the two sensation seeking scores (Pearson's product-moment correlation, p=0.13). Skiers of advanced/expert ability demonstrated a preference for more challenging blue (36%) and black (43%) terrain, while listening to music was popular among beginners/intermediates (77%) and skiers under 30 years old (89%). Univariate analysis revealed no further significant relationships between personal factors. Principal component analysis of participant’s responses to REP scale items (see Appendix B) produced five principal components that were interpreted to represent the general motivation themes of Skill and Thrill (24% of observed variance) Exercise (12%), Scenery (12%), Socializing (11%), and Showing off (11%). Overall, the five principal components accounted for a total of 70% of the observed variance in motivation factors (Table 2).
Table 2 - Standardized factor loading and explained variance for rotated principal components of motivation questions

<table>
<thead>
<tr>
<th>I ski/snowboard</th>
<th>Skill and Thrill</th>
<th>Exercise</th>
<th>Scenery</th>
<th>Socializing</th>
<th>Showing off</th>
</tr>
</thead>
<tbody>
<tr>
<td>...to get exercise</td>
<td>0.07</td>
<td>0.88</td>
<td>0.14</td>
<td>0.00</td>
<td>0.08</td>
</tr>
<tr>
<td>...to keep physical fit</td>
<td>0.19</td>
<td>0.89</td>
<td>0.11</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>...to view the scenery</td>
<td>0.17</td>
<td>0.14</td>
<td>0.92</td>
<td>0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>...to view the scenic beauty</td>
<td>0.17</td>
<td>0.15</td>
<td>0.91</td>
<td>0.13</td>
<td>-0.01</td>
</tr>
<tr>
<td>...to be with members of my group</td>
<td>-0.05</td>
<td>-0.09</td>
<td>0.23</td>
<td>0.77</td>
<td>0.19</td>
</tr>
<tr>
<td>...to be with friends</td>
<td>0.19</td>
<td>0.06</td>
<td>-0.05</td>
<td>0.79</td>
<td>0.07</td>
</tr>
<tr>
<td>...to become better at skiing or snowboarding</td>
<td>0.55</td>
<td>0.10</td>
<td>-0.03</td>
<td>0.44</td>
<td>-0.04</td>
</tr>
<tr>
<td>...to develop my skills and abilities</td>
<td>0.61</td>
<td>0.14</td>
<td>0.02</td>
<td>0.36</td>
<td>0.13</td>
</tr>
<tr>
<td>...to test my abilities</td>
<td>0.71</td>
<td>0.11</td>
<td>0.19</td>
<td>0.00</td>
<td>0.18</td>
</tr>
<tr>
<td>...to learn what I am capable of</td>
<td>0.69</td>
<td>-0.04</td>
<td>0.11</td>
<td>-0.22</td>
<td>0.16</td>
</tr>
<tr>
<td>...to have thrills</td>
<td>0.74</td>
<td>0.08</td>
<td>-0.02</td>
<td>0.28</td>
<td>-0.15</td>
</tr>
<tr>
<td>...to experience excitement</td>
<td>0.78</td>
<td>0.11</td>
<td>0.10</td>
<td>-0.03</td>
<td>-0.09</td>
</tr>
<tr>
<td>...to test my endurance</td>
<td>0.65</td>
<td>0.49</td>
<td>0.13</td>
<td>-0.01</td>
<td>0.16</td>
</tr>
<tr>
<td>...to gain a sense of accomplishment</td>
<td>0.66</td>
<td>0.08</td>
<td>0.24</td>
<td>0.27</td>
<td>0.15</td>
</tr>
<tr>
<td>...to have others think highly of me for doing it</td>
<td>0.04</td>
<td>0.07</td>
<td>-0.04</td>
<td>0.05</td>
<td>0.89</td>
</tr>
<tr>
<td>...to show others I can do it</td>
<td>0.13</td>
<td>0.09</td>
<td>0.03</td>
<td>0.19</td>
<td>0.87</td>
</tr>
<tr>
<td>Proportion of Variance</td>
<td>0.24</td>
<td>0.12</td>
<td>0.12</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Cumulative Variance</td>
<td>0.24</td>
<td>0.36</td>
<td>0.48</td>
<td>0.59</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Skiing took place on 23 days with an even distribution across CTRL and HUD test sessions (Table 3). Weather conditions were mostly ‘nil precipitation’ (43%) or ‘snow’ (35%), with visibility either unlimited (48%) or variable (30%). Participants skied on 51 unique run sections in total, classified as green (27%) or blue (47%) or black (25%) terrain, according to the ski area’s rating system (Figure 3).
Table 3 - Number of completed run sections per date and experiment stage.

<table>
<thead>
<tr>
<th></th>
<th>CTRL</th>
<th>HUD1</th>
<th>HUD2</th>
<th>HUD3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/3/2014</td>
<td>61</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>61</td>
</tr>
<tr>
<td>3/7/2014</td>
<td>124</td>
<td>37</td>
<td>0</td>
<td>0</td>
<td>161</td>
</tr>
<tr>
<td>3/8/2014</td>
<td>107</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>119</td>
</tr>
<tr>
<td>3/9/2014</td>
<td>196</td>
<td>43</td>
<td>0</td>
<td>0</td>
<td>239</td>
</tr>
<tr>
<td>3/10/2014</td>
<td>317</td>
<td>281</td>
<td>0</td>
<td>0</td>
<td>598</td>
</tr>
<tr>
<td>3/11/2014</td>
<td>45</td>
<td>64</td>
<td>0</td>
<td>0</td>
<td>109</td>
</tr>
<tr>
<td>3/12/2014</td>
<td>21</td>
<td>0</td>
<td>33</td>
<td>45</td>
<td>99</td>
</tr>
<tr>
<td>3/14/2014</td>
<td>52</td>
<td>171</td>
<td>186</td>
<td>103</td>
<td>512</td>
</tr>
<tr>
<td>3/15/2014</td>
<td>46</td>
<td>177</td>
<td>0</td>
<td>0</td>
<td>223</td>
</tr>
<tr>
<td>3/16/2014</td>
<td>39</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>39</td>
</tr>
<tr>
<td>3/17/2014</td>
<td>56</td>
<td>147</td>
<td>241</td>
<td>28</td>
<td>472</td>
</tr>
<tr>
<td>3/18/2014</td>
<td>0</td>
<td>0</td>
<td>118</td>
<td>0</td>
<td>118</td>
</tr>
<tr>
<td>3/21/2014</td>
<td>0</td>
<td>0</td>
<td>102</td>
<td>156</td>
<td>258</td>
</tr>
<tr>
<td>3/22/2014</td>
<td>45</td>
<td>47</td>
<td>117</td>
<td>96</td>
<td>305</td>
</tr>
<tr>
<td>3/23/2014</td>
<td>0</td>
<td>51</td>
<td>76</td>
<td>107</td>
<td>234</td>
</tr>
<tr>
<td>3/24/2014</td>
<td>0</td>
<td>0</td>
<td>81</td>
<td>160</td>
<td>241</td>
</tr>
<tr>
<td>3/29/2014</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>53</td>
<td>65</td>
</tr>
<tr>
<td>3/30/2014</td>
<td>0</td>
<td>0</td>
<td>71</td>
<td>90</td>
<td>161</td>
</tr>
<tr>
<td>3/31/2014</td>
<td>0</td>
<td>0</td>
<td>24</td>
<td>88</td>
<td>112</td>
</tr>
<tr>
<td>4/1/2014</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>116</td>
<td>116</td>
</tr>
<tr>
<td>4/4/2014</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>4/5/2014</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>4/6/2014</td>
<td>0</td>
<td>0</td>
<td>44</td>
<td>108</td>
<td>152</td>
</tr>
<tr>
<td>Total</td>
<td>1109</td>
<td>1030</td>
<td>1105</td>
<td>1207</td>
<td>4451</td>
</tr>
</tbody>
</table>

The final dataset for statistical analysis contained 4,451 unique run section passes containing speed quantile calculations from 50% to 100% (in 5 percentage point intervals).
4.2. Multivariate regression analyses of influences on speed

Mixed-effects regression analyses of influences on skiing speed revealed four factors that have a positive effect on speed. Main effects against the base level (beginner/intermediate; flat to moderately steep run section; groomed; good visibility) show that advanced/expert ability, listening to music, skiing on a long straight section, and skiing near a lift station, are all associated with faster speeds (Table 4). Slower speeds are associated with six factors: skiing on a treed run, on steep and steepest terrain, on ungroomed terrain, while visibility is limited, and during HUD use. These patterns are consistent at the 95% and 50% quantiles. Except for the effect of skiing ability, no significant main effects were found for any personal characteristics including age, gender, BSSS, CSSQ or REP scale principle components.
Table 4 - Parameter estimates for 95% and 50% quantile speed linear mixed effects models.

<table>
<thead>
<tr>
<th>a) Fixed effects</th>
<th>95 percentile model</th>
<th>50 percent model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Intercept)</td>
<td>3.069</td>
<td>2.725</td>
</tr>
<tr>
<td>Flat or Moderate steep (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Steep</td>
<td>-0.133</td>
<td>-0.178</td>
</tr>
<tr>
<td>Steepest</td>
<td>-0.288</td>
<td>-0.377</td>
</tr>
<tr>
<td>Yes (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>No</td>
<td>-0.233</td>
<td>-0.238</td>
</tr>
<tr>
<td>Beginner/intermediate (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Advanced/expert</td>
<td>0.319</td>
<td>0.311</td>
</tr>
<tr>
<td>Unlimited or Variable (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Limited</td>
<td>-0.191</td>
<td>-0.228</td>
</tr>
<tr>
<td>No (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Yes</td>
<td>0.176</td>
<td>0.211</td>
</tr>
<tr>
<td>No (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Yes</td>
<td>0.118</td>
<td>0.213</td>
</tr>
<tr>
<td>No (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Yes</td>
<td>0.235</td>
<td>0.264</td>
</tr>
<tr>
<td>No (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Yes</td>
<td>-0.129</td>
<td>-0.203</td>
</tr>
<tr>
<td>First time use</td>
<td>0.019</td>
<td>0.052</td>
</tr>
<tr>
<td>Second time use</td>
<td>0.024</td>
<td>0.066</td>
</tr>
<tr>
<td>Third time use</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>No (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Yes</td>
<td>0.096</td>
<td>0.071</td>
</tr>
<tr>
<td>HUD use x Long, straight run section</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>HUD other types of run section (Base)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>HUD on long, straight section</td>
<td>0.096</td>
<td>0.071</td>
</tr>
</tbody>
</table>
### HUD use x Visibility

<table>
<thead>
<tr>
<th>HUD during unlimited or variable visibility (Base)</th>
<th>0.000</th>
<th>0.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>HUD during limited visibility</td>
<td>0.102</td>
<td>0.045</td>
</tr>
</tbody>
</table>

### Skiing ability x Groomed

<table>
<thead>
<tr>
<th>Advanced/expert on groomed run (Base)</th>
<th>0.000</th>
<th>0.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced/expert on not groomed run</td>
<td>0.121</td>
<td>0.033</td>
</tr>
</tbody>
</table>

### Skiing ability x Music

<table>
<thead>
<tr>
<th>Advanced/expert not listening to music (Base)</th>
<th>0.000</th>
<th>0.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced/expert listening to music</td>
<td>-0.214</td>
<td>0.048</td>
</tr>
</tbody>
</table>

### Skiing ability x HUD use

<table>
<thead>
<tr>
<th>Advanced/expert without HUD (Base)</th>
<th>0.000</th>
<th>0.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced/expert with HUD (Base)</td>
<td>0.050</td>
<td>0.022</td>
</tr>
</tbody>
</table>

### Skiing ability x HUD learning effect

<table>
<thead>
<tr>
<th>Advanced/expert using HUD for first time</th>
<th>0.072</th>
<th>0.023</th>
<th>0.002</th>
<th>0.026</th>
<th>0.028</th>
<th>0.360</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced/expert using HUD for second time</td>
<td>-0.031</td>
<td>0.023</td>
<td>0.171</td>
<td>-0.048</td>
<td>0.028</td>
<td>0.084</td>
</tr>
<tr>
<td>Advanced/expert using HUD for third time (Base)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

### b) Random intercept effects

<table>
<thead>
<tr>
<th></th>
<th>95 percentile model</th>
<th>[50]-percentile model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variance</td>
<td>SD</td>
<td>Variance</td>
</tr>
<tr>
<td>Run section</td>
<td>0.007</td>
<td>0.081</td>
</tr>
<tr>
<td>Participant</td>
<td>0.043</td>
<td>0.208</td>
</tr>
<tr>
<td>Day</td>
<td>0.008</td>
<td>0.088</td>
</tr>
<tr>
<td>Residual</td>
<td>0.053</td>
<td>0.231</td>
</tr>
</tbody>
</table>
While main effects for HUD use show a negative overall effect on skiing speeds at the 95% quantile and the 50% quantile, the results are sensitive to ability level, terrain type, and the influence of a short-term learning effect. The interaction between HUD use and advanced/expert ability level indicates that the negative effect of HUD use on speeds is significantly reduced for advanced/expert skiers. Furthermore, the positive interaction between HUD use and long, straight run sections highlights that the effect of HUD use is particularly positive on long, straight skiing terrain.

A short-term learning effect associated with HUD use is detected for beginner/intermediate and advanced/expert skiers, but with contrasting outcomes. During first HUD use, beginners/intermediates slightly increase median speed, but this effect weakens towards maximum speed (Figure 5). Advanced/expert skiers also increase median speed during first HUD use, but in their case this effect strengthens towards maximum speed (Figure 5). However, the positive effect of HUD use on speed for advanced/expert skiers is short-lived. By their second HUD session, advanced/expert skiers decrease maximum and median speed in comparison to the long-term effect of HUD use.
Figure 5. **Point estimates for HUD related main and interaction effects with skiing ability for different speed quantile models with 90% (darkest grey) and 95% (light grey) and 99% (lightest grey) confidence intervals.** Point estimates are coloured according to their significance (ns: white; p-value <0.1: yellow; <0.05: orange; <0.01: red).

The results also show that listening to music affects skiing speeds significantly. However, this effect is also sensitive to ability level. Main effects for listening to music against the base level show a positive effect on maximum and median speeds. However, negative interactions between listening to music and advanced/ expert skiing ability effectively cancel out the main effect, resulting in no significant overall effect for listening to music in this group.
4.3. Illustration of overall influence of HUD and listening to music on skiing speeds on long straight sections

To better illustrate the overall effect of HUD, skiing speeds for all speed quantiles and stages of experiment (CTRL, HUD1, HUD2, HUD3) were calculated for both beginner/intermediate and advanced/expert skiers while skiing on long, straight run sections (Figure 6.). While there is no observed effect of first HUD use on beginner/intermediate skiers’ 100% quantile speeds when skiing on long, straight run sections, a small negative long-term effect on skiing speed is observed towards 50% quantile speeds. In contrast, advanced/expert skiers demonstrate a strong increase in 100% quantile speeds during first HUD use on long straight run sections, with the effect decreasing slightly towards 50% quantile speeds. The skiing speeds of beginner/intermediate skiers on long, straight run sections do not change significantly during subsequent HUD sessions, whereas the skiing speeds of advanced/expert skiers during HUD2 and HUD3 return to levels observed during to CTRL sessions.
Figure 6. Calculated speed values on a long, straight run section for speed quantiles at all stages of the experiment (CTRL, HUD1, HUD2, HUD3) for beginner/intermediate (blue) and advanced/expert (red). Panel A shows 50% and 100% quantiles with 95% prediction intervals in gray. Dashed line shows speed value during CTRL as reference. Panel B shows speed values for all quantiles.
The overall effect of listening to music on beginner/intermediate skiers while skiing on a long, straight run section is illustrated in Figure 7. Listening to music dramatically increases maximum 100% quantile speeds, and this effect is maintained towards 50% quantile speeds.

**Figure 7.** Calculated speed values for beginner/intermediate participants with music (green) and without music (purple) on a long, straight run section for all speed quantiles at all stages of the experiment (CTRL, HUD1, HUD2, HUD3).
Chapter 5.

Discussion

5.1. HUD effect on speed

The results of our study show that the use of HUD goggles does not result in a long-term increase of skiing speeds. By employing a mixed-effects model to analyze the behaviour of individuals across speed quantiles from 50% to 100%, we reveal a complex picture of interactions between personal and external factors. The results show that HUD use is just one among many other important influences on speed, and that the interactions between these influences are often more important than the presence of any single factor. Our findings therefore suggest that the concerns that HUD use might increase risk-taking related to speed behaviour (Dickson et al., 2011) need only be considered in situations where particular personal (advanced/expert) and external (long, straight run sections) factors are present.

5.2. HUD effect, personal factors, and risk taking

Higher ability level is associated both with higher skiing speeds in general and with a significant effect of HUD use on skiing speeds. Advanced/expert skiers appear to benchmark ‘personal best’ speeds during first HUD use, particularly when skiing on long, straight run sections. In contrast, maximum skiing speeds among beginner/intermediate skiers do not substantially change with HUD use, even on long, straight run sections (Figure 6.). In fact, we observed a small, but significant decrease in the long-term 50% quantile skiing speeds. In this user group, low skiing ability is likely the primary factor limiting skiing and snowboarding speeds (Dickson et al., 2012). The extra cognitive demand required to use HUD goggles may further hinder beginner/intermediate skiers in
the same way that technology use is known to distract inexperienced drivers (Lee, 2007; Wikman, Nieminen, & Summala, 1998). For managers, our findings emphasize the need to address risk-taking behaviour among higher ability level skiers.

Surprisingly, age and gender did not predict higher speeds as suggested by previous research (Shealy, Ettlinger, & Johnson, 2005; Ruedl et al., 2010; Ruedl, et al., 2012). In addition, higher sensation seeking scores were not associated with faster speeds during HUD use in this study. We believe this is due to our small and relatively homogeneous sample in terms of demographics, and because our sample was primarily motivated by “Skills and Thrills”. Participants in downhill skiing typically record generally high SS scores (Zuckerman, 2007) which suggests that the scale has been normed on relatively lower risk takers in comparison to extreme sports participants (Slanger & Rudestam, 1997). In contrast, participants in everyday activities tend to demonstrate much greater variation in sensation seeking. For example, research into driving speeds illustrates both heterogeneity in sensation seeking and a very clear relationship between increasing SS scores and faster driving speeds (Zuckerman, 2007). This means sensation seeking – in particular Thrill and Adventure Seeking - may be less useful to resort managers as a predictor of skiing speed in the same way that sensation seeking also fails to predict injury risk in downhill skiing (Bouter, Knipschild, Feij, & Volovics, 1988).

5.3. HUD use and injuries

The ‘novelty effect’ of first time HUD use on advanced/expert users may represent greater risk given that faster skiing speeds have been associated with serious injuries (Shealy & Thomas, 1996; Zuckerman, 2007; Hagel, Pless, Goulet, Platt, & Robitaille, 2005; Macnab et al., 1998). While the effect does not persistent during subsequent HUD sessions (Figure 6.), previous research indicates that travelling at excessive speeds could potentially increase injury risks (Macnab et al., 1998), and that accidents at extreme speeds might even result in fatalities (Shealy & Thomas, 1996). The observed pattern of increased maximum speed during the first day of HUD use by advanced/expert users, and the subsequent normalization of skiing behaviour, also shows some similarities with occasional helmet use. Research indicates that while
helmet use in skiing does not increase risky behaviour overall (Scott et al., 2007; Ruedl et al., 2010), occasional helmet use by males can increase risk-taking (Ružić & Tudor, 2011). Managers must make specific efforts to monitor and manage skier speed in order to reduce risks associated with novelty effects.

5.4. Maximum skiing speeds

The maximum skiing speed observed in our study was 117 km/hr, which was reached by a participant during their first HUD session. This observation is in line with the general trend towards higher skiing speeds. Average skiing speed has increased from 34.7 km/h in the 1970s (Shealy et al., 2005) to 48.2 km/h in 2013 (Ruedl et al., 2013). Dickson et al. (2011) shows that average maximum speeds have reached 62.0 km/h and top speeds now exceed 100 km/h, which is consistent with what we measured in our study. Skier preferences for faster experiences, and the safety concerns associated with this behaviour, is an issue managers must continue to monitor and address in the future.

5.5. Other technology use by skiers

To our knowledge, the effect of listening to music while skiing has not been examined systematically so far. Our analysis demonstrates that beginner/intermediate users ski significantly faster (at all quantiles) when listening to music, however these results should be treated with caution (see Limitations in Section 5.7.). A positive effect of listening to music on speed has also been shown for running (Edworthy & Waring, 2006) and cycling (Atkinson et al., 2004). Interestingly, this effect was not observed among advanced/expert participants in our study. We attribute the difference in the effect of music and HUD on skiing speeds to the fact that listening to music does not require additional cognitive effort and primarily alters the mood of the listener. While listening to upbeat music might provide a mental boost to beginner/intermediate skiers and push them to potentially ski beyond their abilities, advanced/expert skiers do not respond to this stimulus in the same way because they are likely mainly motivated by the skiing activity itself and already skiing as fast as they can. Recent research on
snowboarders in terrain parks indicates that while listening to music is associated with lower odds of injury, it is also associated with increased risk of an injury requiring emergency department hospital treatment (Russell et al., 2014), highlighting the important difference between injury frequency and severity.

The use of ski apps has anecdotally also been linked to reckless skiing and injuries. A recent case in Western Canada, for example, involved a young female skier badly injured – sustaining multiple fractures to her leg, pelvis and face - after crashing into a tree while skiing at high speed while using a ski app (Strachan, 2016). While our study did not explicitly study the effect of ski apps on skier behaviour, our results suggest that ski apps could potentially affect the maximum speeds of advanced/expert users as these apps also allow users to monitor their personal bests. However, our results also indicate that the effect might be limited to first time use only. Furthermore, the effect of ski apps might be reduced because they do not present users with skiing metrics in real time while skiing in the same way as HUD goggles do.

5.6. Implications for ski resort management

This research advances ski resort managers’ general understanding of influences on skiing speeds by examining the topic with a detailed multivariate perspective that includes interactions between individual contributing factors. The results of our study show that skiing speeds are affected by a wide range of external factors including run steepness, presence of trees, grooming status, distance to lift stations and visibility. Study participants skied significant slower on treed runs, steeper terrain, ungroomed runs, further away from lift stations and during periods with limited visibility. Long, straight open run sections that are groomed are particularly inviting for skiers of all ability levels to ski fast. Furthermore, runs with these characteristics are used by advanced/expert skiers to test the HUD functionality when using their goggles for the first time.

These results emphasize the important role managers can play in reducing risk through terrain management and communications. Areas of particular concern are long, straight open run sections that coincide with mixed ability zones or areas of high skier
density due to merging runs or proximity to lift stations. Current management techniques for controlling speed in these areas include marking them as “slow zones”, and installing mesh fences (Dickson et al., 2012). Our results suggest that in addition to these practices, terrain management techniques including narrower trails and less grooming in these areas may reduce skier speed. Resort managers might also consider taking advantage of new technology use to deliver warning messages to HUD goggle or ski app users approaching a slow zone at excessive speeds. Concerns regarding visual distraction (Langran, 2013) might be mitigated by delivering warnings through audio (e.g. beeps) or sensory (e.g. vibrate) functions that take advantage of the technology embedded in a skier’s cellphone or lift pass.

Despite widespread use of GPS and GIS in outdoor recreation and conservation management (Orellana, Bregt, Ligtenberg, & Wachowicz, 2012; Taczanowska, Muhar, & Brandenburg, 2008; D’Antonio et al., 2010; Leung, Walden-Schriener, & Miller, 2012), many ski resort managers have so far not employed this technology to understand the spatial activity of visitors on the mountain. However, our study confirms the efficacy of using these techniques to monitor and analyze visitor behaviour in resorts. Ski managers could analyze skier speed and spatial behaviour based on Radio-Frequency Identification (RFID) & GPS enabled lift pass data in order to assess safety concerns in certain locations. Ski managers might also use spatial data associated with individual skier behaviour to assist with rapid location of visitors in emergency rescue situations. GPS technology is currently used at a number of Canadian resorts including Whistler Blackcomb, Big White, and Tremblant to track children during lessons, providing the instructor with live information on the location of each pupil (Flaik, 2016). Resort managers may consider integrating a GPS tracking function into all lift passes for the most comprehensive view of skier behaviour.

5.7. Limitations

Due to the small size (n=27), the recruitment process (convenience sample) and the focus on a single ski area, participants in this study cannot be considered representative of the skiing population in general. The fact that our analysis did not confirm significant effects of age, gender, BSSS, and CSSQ on skiing is likely the result
of our small and relatively homogeneous sample. Furthermore, our study likely attracted participants with a higher than average interest in technology, which also introduces a potential bias. However, as a result our sample likely represents potential HUD owners better than a random sample.

The observed long-term negative effect of HUD goggles among beginner/intermediate skiers could potentially be caused by participants’ unfamiliarity with skiing with a goggle in general. The reduced field of vision associated with wearing goggles might have influenced some participants to adopt more cautious behaviour and reduce speed regardless of the HUD functionality. However, we did not ask participants if they typically use goggles while skiing and are therefore unable to examine this effect.

Results related to listening to music should be treated with caution since our study was not explicitly designed to examine this effect, and we did not control for music in terms of tempo, intensity, or volume.
Chapter 6.

Conclusions

The objective of this study was to determine if HUD goggle use affects skiing speeds, and if personal factors (e.g., gender, skiing ability) and external factors (e.g., terrain characteristics, weather conditions) moderate the effect of HUD use. We hypothesized that HUD use would increase maximum speed, but not median speed.

This study finds no significant overall long-term effect for HUD use on skiing speeds. However, there is a time sensitive effect associated with HUD use when certain personal and external factors are present. During first HUD use, advanced/expert users ski significantly faster than normal, particularly when skiing on long, straight run sections. However, the novelty effect associated with HUD use soon wears off, and advanced/expert users return to normal speed behaviour during subsequent HUD use. In contrast, beginner/intermediate skiers do not increase maximum speed during HUD use, but do demonstrate a small but significant decrease in long-term median skiing speeds.

6.1. Summary of key management recommendations

Managers should be aware that HUD technology is likely to encourage advanced/expert skiers to push their personal best speeds, at least during first use. If managers are concerned that this behaviour will place users or those around them at risk, they should consider new or revised policies and practices (e.g., patrols, speed warning signs) to mitigate any safety issues. Particular attention should be given to long, straight open run sections that invite skiers to benchmark their ‘personal best’ maximum speeds. However, based on the results of this study, we do not believe managers need to consider a broader policy to address concerns related to excessive speed during HUD
use. Listening to music also demonstrated a strong positive influence on speeds for beginner/intermediate, but not advanced/expert skiers.

6.2. Potential opportunities

Given that HUD goggle use does not appear to be a persistent risk factor in terms of excessive speed, managers might consider how providing geo-targeted information via HUD goggles could improve the visitor experience. For example, delivering lift wait times and slope congestion information via HUD goggles could help users avoid known satisfaction issues such as long lift lines (Perdue, 2002) and safety concerns associated with overcrowded slopes (Clydesdale, 2007).

Some resorts are already making significant efforts to take advantage of location-based technology to improve the visitor experience. By leveraging their existing investment in RFID enabled lift passes and a resort ski app, Vail Resorts now offer a new software product – “EpicMix Time” – that enables skiers to avoid long lift lines by viewing up-to-the-minute line times at 55 lifts and gondolas across the resort. By combining GPS trail maps with lift-wait information, managers at the resort hope to help guests better navigate the mountain and find the best terrain options to maximize their day (Vail Resorts, 2015). In another example, Whistler Blackcomb now offer both a cellphone app for run tracking and lift open/close alerts, and an RFID lift pass-based game called “WB+” that challenges users to reach new personal best scores in terms of distance, vertical, and other participation metrics (Whistler Blackcomb, 2016). Managers should be aware that while these features appear to attract some users, they also deter others who feel GPS tracking invades their privacy. For example, in Vail a secondary market has emerged selling RFID “shields” to prevent the RFID tag from being used to track behaviour while on the slopes (Finley, 2010).

Managers may also consider opportunities to harness GPS data to improve safety. By collecting and analyzing large location-based datasets of skier behaviour, managers might find new ways to manage human and physical risk factors. This approach is already underway at Vail resorts, where managers are using a ski app and RFID enabled lift passes to collect skier’s exact location, distance, vertical, and lift usage
(Somerville, 2014), and could be implemented at Whistler Blackcomb to address concerns that “gamifying” the skiing experience may be increasing risky skier behaviour (L. Sampson, personal communication, May 5, 2016).

6.3. Future research

Future research should investigate the distraction potential of HUD goggles (Langran, 2013) with controlled randomized trials providing the best evidence. Given that existing studies show skiers consistently underestimate both mean (Ruedl et al., 2013) and maximum speeds (Dickson et al., 2012), examining the influence of HUD goggles on the ability of users to estimate their speed is another potential research topic.

In addition, managers should pay attention to research that focuses on the relationship between music and skiing speed in more detail. Research into other outdoor recreation pursuits indicates that listening to music has a positive effect on speed (Edworthy & Waring, 2006; Atkinson et al., 2004), while this study suggests the effect may be sensitive to ability level. To verify this, a comprehensive study of the effect of listening to music on skiing speed in the context of personal factors is recommended.

The effect of ski app use on skier behaviour also requires investigation. Given concern among ski resort managers (Strachan, 2016) and the media (Kirby, 2014) that ski app use may cause excessively fast skiing behaviour, the effect on speed should be the primary focus of future research in this area.

Finally, there is no existing research into the influence of wearable cameras on visual distraction, speed, or other forms of risk-taking (e.g. cliff-drops, jumps) behaviour. Resort managers consider cameras another potential cause of increased distraction and risk. For example, in Switzerland the country’s accident prevention bureau warns skiers and snowboarders against using mini-cameras strapped onto helmets to avoid risks associated with attempting to record more exciting video footage, and because of the increased risk of serious head injuries as a result of modifying helmets with camera mounts (Local, 2014). Studies on this topic should be considered in the context of considerable existing research into the efficacy of helmet use (Dickson, Trathen, Terweil,
et al., 2015; Hagel et al., 2005; Macnab et al., 2002; Ruedl et al., 2011; Ruedl, Abart, et al., 2012; Russell et al., 2010; Ružić & Tudor, 2011; Scott et al., 2007; Spicer & Hooper, 2015; Thomson & Carlson, 2015).
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Appendix A.

Study Recruitment

Cypress Mountain Website

Vancouver Sun Website

SFU seeks recruits to test high-tech goggles at Cypress

BY MARY FRANCES HILL  MARCH 12, 2014

MORE ON THIS STORY
- Mountain Collective Pass gives access to best North American resorts
- Cypress launches Family Pass for
Online Sign Up Form: Choosing Test Dates

Sign Up: Wearable Technology Study

Your test days

Every day during the study we will ask you to carry a GPS Trackstick. This small device will record your location throughout the day. There is nothing special you need to do, simply carry it as instructed by the research team and enjoy your day of skiing or snowboarding.

During 3 test sessions you will be asked to use a pair of Head Up Display goggles in addition to carrying the GPS Trackstick. You do not need to perform any special activities or tests. Simply ski or snowboard as you wish. At the end of each day you will be required to fill out a quick online survey.

Booking in

Please review the list below and select the days you are available for testing at Cypress Mountain. You must select 3 days, but test days do not need to be consecutive.

Testing will occur between 9am and 5pm. Test pairs of Head Up Display goggles will be available for pick up from our stand at Cypress Mountain between 8:30am and 1pm.

- Fri Feb 28
- Fri Mar 7
- Fri Mar 14
- Fri Mar 21
- Fri Mar 28
- Fri Apr 4
- Sat Mar 1
- Sat Mar 8
- Sat Mar 15
- Sat Mar 22
- Sat Mar 29
- Sat Apr 5
- Sun Mar 2
- Sun Mar 9
- Sun Mar 16
- Sun Mar 23
- Sun Mar 30
- Sun Apr 6
- Mon Mar 3
- Mon Mar 10
- Mon Mar 17
- Mon Mar 24
- Mon Mar 31
- Mon Apr 7

Changing days - 24 hour notice

We understand plans can change. You will receive an email to log back into this website and change your days if needed. Please try and give us at least 24 hours notice to confirm any changes.

If you have any issues with booking in or changing your days, please email sparker@sfu.ca - we will do our best to accommodate you.

SUBMIT

Online Survey Tools powered by Wufoo
Appendix B.

Online survey

Online Survey: Profile

Survey: Wearable Technology Study

Profile (page 1 of 6)
Please tell us a little about yourself. The following information will allow us to understand how different groups of people use the mountain and how they interact with technology.

What is your year of birth?

What is your gender?
- Male  
- Female

Did you sign up as an 'individual' or 'buddy' participant?
- Individual - I will be the only one using the Heads Up Display goggle.
- Buddy - I will be sharing the Heads Up Display goggle with a buddy.

How many days did you ski or snowboard last season in total?
- 0 days
- 1-5 days
- 6-10 days
- 11-20 days

How many days did you ski or snowboard last season at Cypress Mountain?
- 0 days
- 1-5 days
- 6-10 days
- 11-20 days
When visiting Cypress Mountain, do you typically ski or snowboard? Please assume the snow conditions are reasonable and visibility is acceptable.

- Ski
- Snowboard

How do you rate your skiing ability level?

- Beginner
- Intermediate
- Advanced
- Expert

In what kind of terrain do you spend most of your time when skiing or snowboarding on Cypress Mountain? Please assume the snow conditions are reasonable and visibility is acceptable.

- Green trails
- Blue trails
- Black diamond trails
- Black double diamond trails
- Off-piste areas (e.g., between trails, in the trees)
- Terrain parks

NEXT
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Survey: Wearable Technology Study

Profile (page 3 of 6)

What technology do you use during a typical session of skiing or snowboarding?
This question applies to your use of technology while skiing or snowboarding at any resort, not just Cypress Mountain.
Please check all that apply:

- Cellphone to view resort information (e.g. trail map, snow conditions, lift status etc.)
- Cellphone application or other device to track and view speed, distance, vertical, etc.
- Wearable camera (e.g. GoPro)
- Music player (e.g. MP3 player, cellphone, radio) with headphones
- Heads Up Display google
- Other
- None of the above

Type here

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Survey: Wearable Technology Study

Profile (page 5 of 6)

Please indicate how strongly you agree or disagree with the following statements about your skiing or snowboarding behaviour.

- A 15 - foot high drop off a cliff isn't too high a jump for me.
- I like to push my boundaries when I ski/snowboard.
- I like to ski/snowboard down runs that I have never been down before.
- I like to attempt jumps even if I'm not sure of the quality of the landing area.
- If I lose control, I don't try to immediately slow down, I just go with it.
- I like to ski/snowboard fast.
- I like to ski/snowboard out of bounds.
- If the only way down is a straight line through a narrow pass, I go for it without hesitation even if I know I will have to go fast.
- I am always trying to find new and exciting ways down a run.
- I like to start a run even if I cannot see what lies ahead (i.e., big cornice).

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Survey: Wearable Technology Study

Profile (page 6 of 6)

Please indicate how strongly you agree or disagree with the following general statements.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would like to take off on a trip with no pre-planned routes or timetables.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I would love to have new and exciting experiences, even if they are illegal.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I would like to try bungee jumping.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I like to do frightening things.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I prefer friends who are excitingly unpredictable.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I like wild parties.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I would like to explore strange places.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>I get restless when I spend too much time at home.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
Online Survey: Test Session

Survey: Wearable Technology Study

Test Session 2 (page 1 of 8)

Please enter the date of your second test session. If the test session you are completing this survey for was prior to today, please make sure you enter the correct date.

Date: 2014/11/24

Did you ski or snowboard during your second test session?
- Skiing
- Snowboarding

What was the size of the group you skied or snowboarded with during your second test session?
Please enter the number of people in your group (including yourself).
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- More than 8

Who made most of the decisions (e.g., which trail to take) while skiing or snowboarding during your second test session?
- I made most decisions
- We shared decision making equally
- Other group member(s) made most decisions

Next
Save and exit now

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This survey is invite only, respondents will require a valid invite code to view this survey.

Survey: Wearable Technology Study

Test Session 2 (page 2 of 8)

Did you share the Heads Up Display goggles with anyone during your second test session?

- Yes - with someone who is not participating in this study.
- Yes - with my buddy who is also taking part in this study.
- No - I did not share the test goggles with anyone.

What time did you first share the Heads Up Display goggles during your second test session?

Time: HH:MM AM/PM

NEXT

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Survey: Wearable Technology Study

Test Session 2 (page 3 of 8)

What technology did you use during your second test session while skiing or snowboarding?

Please check all that apply. (There is no need to report the GPS Tracktick provided to you.)

- [ ] Cellphone to view resort information (e.g. trail map, snow conditions, lift status etc.)
- [ ] Wearable camera (e.g. GoPro)
- [ ] Music player (e.g. MP3 player, cellphone, radio) with headphones
- [ ] Cellphone application or other device to track and view speed, distance, vertical, etc.
- [ ] Heads Up Display goggle
- [ ] Other
- [ ] None of the above

Did other group members use any technology while skiing or snowboarding with you during your second test session?

Please check all that apply.

- [ ] Cellphone to view resort information (e.g. trail map, snow conditions, lift status etc.)
- [ ] Cellphone application or other device to track and view speed, distance, vertical, etc.
- [ ] Wearable camera (e.g. GoPro)
- [ ] Music player (e.g. MP3 player, cellphone, radio) with headphones
- [ ] Heads Up Display goggle
- [ ] Other
- [ ] None of my group members used any technology

NEXT

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Survey: Wearable Technology Study

Test Session 2 (page 4 of 8)

Please do not consult any tracking devices (if used) when answering these questions.

Please estimate the number of runs you did during your second test session.
Your answer should be a number only.

Type here

Please estimate your maximum speed during your second test session in km/hr.
Your answer should be a number only.

Type here

Please estimate the total distance you skied or snowboarded during your second test session in km.
Your answer should be a number only.

Type here

Please estimate the total vertical you skied or snowboarded during your second test session in metres.
Your answer should be a number only.

Type here

Next

Save and exit form now

Form Tools powered by flux Surveys

This survey is invite only; respondents will require a valid invite code to view this survey.

Survey: Wearable Technology Study

Test Session 2 (page 5 of 8)

Do you think your maximum speed while skiing or snowboarding during your second test session was higher or lower than when you normally ride at Cypress Mountain?

- My maximum speed was higher than normal.
- My maximum speed was the same as always.
- My maximum speed was lower than normal.

What was the single most important reason for your maximum speed to be lower than normal?

- Snow conditions.
- Poor weather (e.g., rain).
- Poor visibility.
- Terrain availability.
- The speed of my buddy (if applicable).
- The speed of other people in my group (if applicable).
- Number of people on the trails.
- Using a cellphone to view resort information (if applicable).
- Using a wearable camera (if applicable).
- Using a music player with headphones (if applicable).
- Using a cellphone application or other device to track and view speed, distance, vertical, etc. (if applicable).
- Using a Heads Up Display goggle (if applicable).
- Other, please specify...

Type here

NEXT

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Survey: Wearable Technology Study

Test Session 2 (page 6 of 8)

On a scale from 1 to 10, with 10 being a perfect session of skiing or snowboarding, how would you rate the overall quality of your experience during your second test session?

How satisfied were you with the following elements of your second test session?

<table>
<thead>
<tr>
<th>Element</th>
<th>N/A</th>
<th>Very Dissatisfied</th>
<th>Dissatisfied</th>
<th>Neutral</th>
<th>Satisfied</th>
<th>Very Satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freestyle park</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenery and natural features</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snow conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lift wait time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of people on the trails</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trails and terrain available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using the Heads Up Display goalie</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of lifts open</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NEXT

SAVE AND EDIT LATER
Test Session 2 (page 7 of 8)

How much did you enjoy using the following Heads Up Display goggle features during your second test session?

<table>
<thead>
<tr>
<th>Feature</th>
<th>N / A</th>
<th>Not At All</th>
<th>Not Really</th>
<th>Neutral</th>
<th>Somewhat</th>
<th>Very Much</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your location on map</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total vertical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>View resort trail map</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incoming phone call alert</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read incoming text messages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airtime</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>View location of friends on map</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total distance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control music on cell phone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of runs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NEXT

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https://fluidsurvey.com/wearable-technology-survey/77E7_254A84501924_L0429_15384068_107515938191504
Survey: Wearable Technology Study

Test Session 2 (page 8 of 8)

From the statements listed below, which one is the single most important reason you came skiing or snowboarding on the day of your second test session?

Please select one option from the list below.

- To show others I can do it.
- To learn what I am capable of.
- To develop my skills and abilities.
- To test my endurance.
- To participate in this study.
- To be with friends.
- To have thrills.
- To become better at skiing or snowboarding.
- To gain a sense of accomplishment.
- To view the scenic beauty.
- To keep physically fit.
- To test my abilities.
- To experience excitement.
- To be with members of my group.
- To get exercise.
- To have others think highly of me for doing it.
- To view the scenery.

NEXT

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