ABSTRACT

Title of Thesis:	USER INTERFACE CHANGES IN VIRTUAL ENVIRONMENTS AFFECT THE PERCEIVED RESPONSES OF INDOOR CYCLISTS
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Virtual reality is becoming mainstream in areas such as entertainment, medicine and training. However, the affect on a user's perceived states are still to be fully understood. This study aims to add to the existing body of research by examining changes in user interfaces and the affect on perceived responses. Subjects in the study were exposed to two virtual environments, while undertaking a physical exercise task. Their perceived responses were captured through a combination of

interviews, observations, and surveys. This differs from previous studies in that it is capturing the perceived differences *between* the environments themselves. The results highlighted that the content of the environments resulted in a variety of interesting, and unexpected, perceived responses.

USER INTERFACE CHANGES IN VIRTUAL ENVIRONMENTS AFFECT THE PERCEIVED RESPONSES OF INDOOR CYCLISTS

by

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List of Abbreviations

ECG	Electrocardiogram
FPS	First-person Shooter
HCW	High Cognitive Workload
HMD	Head-Mounted Display
LCW	Low Cognitive Workload
MHR	Mean Heart Rate
MRG	Multi-Resolution Grid
POV	Point of View
RPE	Rating of Perceived Exertion
VE	Virtual Environment
VR	Virtual Reality

1. Introduction

Virtual environments are becoming more prevalent in day to day society, due to a reduced barrier to entry brought about by decreased price points, smaller equipment sizes and a veritable explosion in supporting software. However, there is little study data available to understand the affect on human perception when experiencing different virtual environments.

The majority of available data relates to comparing non-virtual environments to virtual environments, and this study aims to explore perceived responses when a user is exposed to two virtual environments when conducting a common task.

In this study I hypothesize that interface differences in virtual environments will have differing perceived impacts on users. To test this, users conducted a cycling task while exposed to two different VEs. I found that perceived changes included impacts on visual cues, the perception of control, emotional and physical responses, and task completion.

2. Related Work

Types of Virtual Environments & Physiology

There is a vast amount of research surrounding virtual environments (VE) consisting of virtual, augmented, and mixed realities, simulations, and various gaming platforms. These studies primarily examine how the shift from an external to a virtual environment elicits various physiological and/or perceived responses within subjects, including changes in heart rate, exertion, skin resistance, heart rate variability, electroencephalography, skin conductance response, and cortisol levels. My study, which captures physiological and qualitative data, focuses specifically on participants' perceived responses when moving between two different virtual reality interfaces.

The body of research on responses to VEs includes a variety of simulated environments, the most common of which are horror (or fear), flight, driving, and shooting. In all these environments, researchers have found a correspondence between the simulated environments and perception as well as physiological measurements and physiological stress markers. Such studies utilize various methods to elicit responses, including fear, stress, and excitement.

Simulation studies generally support the broad hypothesis that immersing someone in a virtual environment of any type elicits various responses to the presented stimuli. The majority of existing studies, however, compare baseline sets of psychological and physiological data (recorded prior to immersion in the virtual environment) with data gathered after immersion, with the purpose of measuring differences between the baseline and simulation. Few studies, however, seek to understand whether similar responses occur when shifting between simulated interfaces. My study seeks to address this need by comparing subjects' perceived responses upon shifting between two virtual interfaces.

Horror-Based Virtual Environments

Horror- or fear-based virtual environments are designed to shock users and play on their fears. Horror-based virtual environments utilize techniques commonly found in movies, such as restricting viewpoints, limiting what can be seen (e.g., via darkness, fog), and setting up "jump scares" whereby something appears to the viewer seemingly out of nowhere. In each case, the desired goal is to shock or scare the participant and thereby evoke fear, terror, or panic.

Throughout the literature, horror-based techniques have been used to place participants in uncomfortable situations, whether directly due to the VE or due to an underlying fear or phobia (such as fear of flying). Examples of such studies include fear simulations by Weiderholden et al. (1998), pit room studies by Meehan (2002, 2003), and a dental drilling simulation by Raghav (2016).

Rovira et al. studied responses to fear in the context of simulated violence by measuring skin conductance, heart rate, and heart rate variability for 34 participants, all of whom watched or heard a virtual character receiving electric shocks (Rovira, Swapp, Spanlang, & Slater, 2009). Of the participants who watched the character receive shocks, a majority exhibited clear signs of elevated stress as measured by heart rate. The researchers concluded that well-constructed VR interfaces simulating violence could indeed illicit a strong physiological response as well as lead to perceived response differences.

Several studies have also examined whether a physiological response occurs in simulated environments designed to provoke a particular phobia. For example, Moore et al. (2002) studied panic and agoraphobia in virtual worlds by analyzing phobic and non-phobic participants' physiological responses (skin temperature, heart rate, respiration, and skin conductance) in the context of a "virtual medicine" simulation. The responses were measured using the I330-C2 computerized biofeedback apparatus. Upon initial exposure, an increase in heart rate and other physiological stress responses were observed, although a decrease in heart rate was found after prolonged exposure to the fear-inducing virtual environment (Moore, Wiederhold, Wiederhold, & Riva 2002). Additional phobia studies have used VE phobia simulations to examine subjects' physiological responses. For example, Slater et al. (2009) studied physiological responses to illumination and shadows within a "pit room" by recording ray tracing, in which shadows and reflections are rendered, and ray casting, in which the illumination of the environment does not produce or display any type of shadow effects. The measured physiological responses included heart rate and skin conductance response. The authors demonstrated a significant increase in heart rate differences from the baseline for ray tracing but found no significant difference from the baseline heart rate with respect to ray casting (Slater, Khanna, Mortensen, & Yu, 2009).

Two additional examples of studies looking at fear-induced stress in virtual environments are Meehan's 2002 and 2003 longitudinal studies on presence and latency, which specifically measured heart and skin conductance responses. Testing subjects' reactions to two different VEs, a training room and a pit room, Meehan found increases in both heart rate and skin conductance on first exposure, although like Moore he observed a decrease in these measurements over multiple exposures to the same fear-inducing environment (Meehan, 2002, 2003).

One important factor to consider in gauging physiological and/or perceived responses to VR fear environments is that individuals respond in markedly different ways. Raghav et al. (2016), in the first stage of a long-term fear- and phobia-based longitudinal study using an Oculus dev kit 2 with HMD, simulated a dental experience in which participants were exposed to five different virtual scenarios (a drill with no sound, a drill with sound, a mirror, a syringe, and idle or baseline). During this study, the only physiological measure taken was heart rate, measured after exposure to the VE at 1 week, 3-month, and 6-month intervals. Although the authors did not report specifically on heart rates during this first stage of the study, they concluded that physiological responses varied considerably among individuals, suggesting the importance of individual variability in assessing outcomes (Raghav, 2016).

Overall, these studies confirm that fear-based simulations elevate stress levels and affect physiological markers such as heart rate. Significantly, however, only a handful of studies looked at differences in responses when shifting between virtual interfaces. Thus, an unanswered question is whether moving between VR interfaces, as opposed to moving from an external baseline to an internal interface, produces similar changes in responses. My study tackles this question by measuring whether perceived responses and exertion differences occur when shifting between two virtual environments.

Flight-Based Virtual Environments

Flight-based virtual environments typically place the participant in an experience that simulates flying a vehicle or flying within a vehicle. These can range from the complex, such as Microsoft's "Flight Simulator X" (Dovetail Games, 2006) which is used for training aspiring pilots, to the basic, such as the "Aquila Bird Flight Simulator," which simply give the viewer the experience of flying (Scott, 2017). In most flying simulations, the user is given control over the flying entity and is able move freely through a 3D environment. Some flying VEs are embedded within the wider world of games. For instance, in the video game "Grand Theft Auto V," players can fly planes, helicopters, jet packs, and even cars (Rockstar Games, 2015).

Most research surrounding the use of flight-based virtual environments measure some type of physiological response, such as heart rate or skin resistance. Literature centered on piloting aircraft in a virtual environment tends to focus on pilots' task-based or cognitive workloads, although heart rates are typically captured in these studies as well. In several studies, the aim was to explore "fear of flying" by utilizing Virtual Reality (VR)-based simulation exposure and then measuring the participants' responses. For example, Wiederhold et al. (1998) captured multiple physiological responses, including heart rate, of subjects who were placed in a fully immersive environment while wearing a Multi-Resolution Grid (MRG) head-mounted display (HMD). Unfortunately, the results were not reported or discussed within the study, leaving the significance of any heart rate response unknown (this data may have been excluded due to the limited number of participants (n=2)) (Wiederhold, Gevirtz, & Wiederhold, 1998). In a different study, however, Wiederhold et al. (2002) compared baseline physiological numbers with responses to flying in a virtual environment and found statistically significant changes in participant heart rates upon first exposure to the simulated flying environment (Wiederhold et al., 2002).

Another flight-based VE study, by Hidalgo-Munoz (2018), used a different procedure but produced similar physiological results. This study set up two virtual environments related to piloting a plane and applied tasks and stressors to increase the cognitive workload of the participants. During the study, heart rate and heart rate variation were recorded within an AL-50 simulator while the participants conducted Low Cognitive Workload (LCW) and High Cognitive Workload (HCW) tasks. The researchers concluded that HCW resulted in an elevated heart rate, both during lower arousal and higher arousal states, and that stress responses were highest for participants who were performing the tasks for the first time (Hidalgo-Munoz et al., 2018).

When measuring heart rate responses in flight simulations, an important factor is the participant's feeling of "presence," which can be described as the sense of realism one experiences during a simulation. For instance, Wiederhold, Jang, Kaneda, et al. (2003) conducted a study of flight-based virtual environments that focused on participants' feeling of presence while traveling on a simulated commercial airplane. The participants were seated as general passengers in the cabin, and heart rate and skin resistance were measured. The results of this study indicated that subjects experienced reductions in stress response, including a decrease in heart rate, when they perceived the VE to be more realistic. Although my study did not measure presence per se, the qualitative responses I received from several of my participants revealed that their perceptions of realism during the simulations were critical to how they processed their VE experience.

Within the flight-based virtual environment literature, no instances were found where researchers modified subjects' experiences within the virtual environments themselves; in all cases, the studies compared a baseline "non-experience" or non-virtual environment to a subject's experience within a virtual environment, and measured the responses that occurred following the shift. By contrast, my study focuses on the changes experienced by the user between virtual interfaces rather than between a non-virtual environment and a virtual interface. Further, among the studies that measured a change in heart rate, all attributed the change to an external factor, such as tasks or existing phobias. Therefore, it remains a relevant question whether modifying the VEs alone, or the interfaces within VEs, may result in physiological and/or perceived changes in the participants.

Driving and Shooting-Based Virtual Environments

In driving-based virtual environments, the participant is usually placed in control of a vehicle from the driver's perspective. Like some flight-based virtual environments, the experience elicits responses from the user as they move through a particular environment. Other simulations are more complex, for instance, the Euro Truck Simulator 2 (SCS Software, 2013) which requires players to handle all of the features of a truck, including turn signals, trailer brakes, gears, and handbrakes.

In one study, researchers recorded the physiological responses of driving in both simulated and on-road driving environments, and found that the mean heart rate

(MHR) showed a significant variability during simulated element-of-surprise events, such as a car pulling out or a stop light suddenly changing (Johnson et al., 2011). Specifically, in both simulated and real-world driving scenarios, the participants demonstrated significant MHR elevation. In a different study of real world and simulated driving environments, researchers measured heart rate using an Electrocardiogram (ECG) and discovered that heart rate increased both in the moving-based simulator and the field driving test compared to the baseline (Carsten & Brookhuis, 2005, pp. 75-77).

An area related to simulated driving research is simulated shooting research, which typically involve a first-person shooter (FPS) participating in a point of view (POV) game. Point of view within most virtual environments, particularly shooting VEs, centers around the “view of the player”—commonly referred to as “first person”—in which the user sees the world through their own eyes. The experience invariably involves some aspect of shooting and/or destruction of virtual environments, players, or objects. Some of the simpler game types involve users destroying objects that block a player’s path as they attempt to move forward, a setup used in “Smash Hit” on Samsung Gear VR (Mediocre, 2014). Other simulations attempt to replicate actual battle scenarios with precision, for instance, “Squad” (Offworld Industries, 2015), which was designed from the ground up to capture combat as realistically as possible. In one shooting study (McCraty & Atkinson (2012), researchers created three simulated police training scenarios and employed 24-hour ECG recordings to measure heart rate and blood pressure changes over time. In all three simulations, they observed a large and rapid increase in heart rate and mean blood pressure.

However, subjects that used the HeartMath technique (in which participants focus their attention on their heart rate and breathing), were able to control their perceived responses within the simulations to a greater degree than subjects in the control group (McCraty & Atkinson, 2012). Another shooting simulation study, by Ross & Humes (2017), measured stress reactions of police officers in deadly simulated scenarios and reported similar increases in heart rate. The study also explored the aspects of perception and misperception within the simulations, noting that as the intensity, as well as the visual and cognitive complexity of the simulations increased, less experienced officers had a greater degree of misperception, and were unable to recall critical details related to the simulation(s). (Ross & Humes, 2017).

Like most of the flight and horror simulation studies, these driving and shooting studies measured changes from baseline to internal simulation rather than between simulations, as my study does. Nonetheless, they provide a foundation for understanding how changes in the user interface—particularly the progression from calm environments to stress-inducing environments—may affect perceived measures. Although my study looks at the perceived changes that occur only between interfaces, the previously mentioned baseline-to-VE studies provided a basis for my hypothesis that changes *between* interfaces within the virtual environments affect perceived responses.

3. Methodology

This study used a within-subjects design, with two conditions based on two virtual environments consisting of Hawaii and Amsterdam. Each participant was tested in each of the two virtual environments and their perceived responses to each environment were captured via observation interviews and survey responses. This qualitative data was then compared for differences.

Recruitment

Participants were recruited throughout the University of Maryland – College Park campus via flyers, emails, student organization listservs, and departmental listservs with the recruitment goal of 30 participants.

Eligibility

Participants 18 years and older, in good health and able to wear a virtual reality (VR) head mounted display (HMD) without eye glasses were eligible. Participants with histories of seizures or epilepsy were excluded for safety reasons.

Subjects

In total, 31 (14 Female (45.11%), 16 Male (51.67%), 1 Nonbinary (3.23%)) people participated. The distribution of the participants by age group was as follows: 18-21 (N=8/25.84%), 21-34 (N=18/58.03%), 35-44 (N=2 /6.46%), 45-54 (N=1/3.23%) and 55-64 (N=2/6.46%) age range. Over half the participants (N=17/54.09%) had previously used a VR headset. Their motivation for using a VR headset was tied between exploration/sightseeing (N=17/33.67%) and gaming (N=17/33.67%). Only

N=11/22.11% of participants exercise as a motivation for using VR and N=5/10.56% indicated “Other” as a motivation.

Equipment & Materials

The Samsung Gear VR was used in conjunction with the Galaxy Note 8, Oculus and YouTube applications with 360 degree videos created specifically for VR. A Schwinn 320 recumbent ergometer equipped with heart rate sensors was also used. Additionally, two surveys and the Borg Rating of Perceived Exertion (RPE) worksheet for capturing perceived exertion, or how hard a person feels their body is working, were used in data collection (Borg 1998).

Surveys

Two surveys for data collection were designed. Survey one was designed to capture general demographic information (age, sex, race), previous experience with a VR headset, motivation for using VR, and if they had any negative experiences while using VR. Survey number two was introduced after both virtual experiences with question one indicating which scenery was observed. The survey included a question inquiring whether the experience had a direct impact on the participant’s perceived effort. In addition, the participants were asked if they had any negative experiences during the study. This included dizziness, nausea, fatigue, headaches, and faintness. An open ended question (Is there any additional information about the virtual environment you would like to provide?) was also included in survey two which allowed for additional comments regarding the scenery and to capture additional qualitative data.

Procedure

Each virtual environment was specifically selected because of its content type and variation. The Hawaii VE was selected as it depicted a more relaxed experience, with scenery which remained largely unchanged throughout the ride. The Amsterdam VE was selected as it depicted a busy city environment, with regular changes in scenery and content. The rationale being that, due to the high degree of variation between the Hawaii scene and the Amsterdam scene, there was a greater chance of discovering differences in perceptual responses between the scenes amongst subjects of the study. These two environments were chosen because of their differences.

Participants were informed of the intent of the study, data collection, and overall confidentiality. Once briefed, participants were screened and asked to sign a consent form and were informed they could end their participation in the study at any time. Upon consent, participants were provided instructions on how to adjust the ergometer, as well as fitting and navigating the VR HMD. Once acknowledged, the participants began the baseline portion of the study in which they cycled for 10 minutes at a perceived moderate effort with no visual stimuli. During this time heart rate and time data points were recorded directly within the ergometer. Upon completion of the baseline, the participants were placed on a 10-minute break, with no visual stimuli, and asked to complete the demographic survey.

Once complete, participants began the virtual environment phases of the study. In phase one, participants were introduced to a virtual cycling experience in Hawaii (see figure 1). To begin, users returned to the ergometer, donned the VR HMD, and repeated a 10 minute cycle through Hawaii in which heart rate, observations, general comments, and time data points were recorded. After the 10 minute cycling session the participants were placed on a 10 minute break. During this break participants were asked to fill out the post virtual experience survey for Hawaii and asked two qualitative questions. Although the participants were instructed "ride" at a perceived moderate effort, question one asked the participant what motivated them, beyond the instructions, to continue at a moderate perceived effort during the scenery. Question two asked if there was anything specific about the interface they would change. Additionally, participants indicated their RPE on the Borg worksheet. During phase two, the participants were introduced to a cycling experience in Amsterdam (See figure 2). To begin this phase, the participants returned to the ergometer, mounted the HMD, and pedaled for another 10 minutes. The same data (heart rate, observations, general comments, and time) was recorded during the cycling session. Upon completion, another break began and the participants answered the same post virtual experience survey but for Amsterdam, along with the same qualitative questions and indicated their RPE on the Borg rating worksheet. The total duration of the study was approximately one hour. Once a participant completed the phases, the recorded data was collected from the ergometer via USB (heartrate, duration) and qualitative questions transcribed. A collection error in capturing heartrate data was later discovered and therefore the results are not reported in this study. Participants received various incentives (Amazon gift cards and snacks) upon completion.

Figure 2-Hawaii VR Cycling View

Figure 1-Amsterdam VR Cycling View

Data Analysis

Interview sessions were transcribed in real-time during each session. Transcriptions were then prepared and annotated in Excel for qualitative data analysis using thematic analysis. Two individuals conducted analysis and a thematic codebook was created using inductive analysis on 100% of the participant data. After initial coding, the two individuals met, discussed and refined the codebook. This was then used as a basis for inter-coder reliability to remove potential bias and resulted in a straight percentage agreement of 91.60%.

Multiple themes initially presented throughout the data. Upon further analysis the following thematic codes emerged (1) Speed and visual cues (2) Control within a VE (3) Complexity and variety of perceived response, and (4) Completion of tasks and goals. Through inductive analysis of the data gathered across all sessions, including questionnaires and interviews, research questions emerged. The results are organized in the following section.

4. Results

Several themes were common across both scenes. However, the subjects' perceived responses across both scenes was the focus and the driving factor when analyzing qualitative data.

<u>Speed & Visual Cues</u>

A common aspect that was observed involved when the virtual environment depicts slowing down or stopping, but the subject had to continue pedaling. In these instances, both a negative physical and emotional response was reported by participants during interview sessions. The negative physical responses reported include symptoms of nausea, dizziness, disorientation, headache and syncope. Each of these symptoms are commonly reported aspects of cyber-sickness. This was more pronounced within the Amsterdam scene, which had a higher frequency of virtual stops, for stop-lights, trains, cross-walks etc. For instance, S01 stated of Amsterdam, "The way in which the speed the video was moving, because a couple of moments when I had to stop virtually (like for a train) I felt really weird because I was still biking". There were 38 responses in Amsterdam alone containing a negative physical and/or emotional response. The responses ranged from general discomfort with the stops, S15 "The stopping is weird", to outright frustration, S10 "It stops again! I want to chew out the cyclist..."

This negative emotional and physical response was also seen with subjects experiencing Hawaii, even though the scene contained very little in the way of "virtual stops". The Hawaii stops depicted a group of riders halting to allow vehicles to pass. This resulted in reports from S14 “Dizziness from stop/go” and “The stops! Hard to keep with all the stops [sic]”.

An additional aspect, that elicited similar responses related to visual cues in the scenes. These included virtual riders “coasting” (i.e. not pedaling), virtual riders were depicted going downhill, or virtual riders at a cadence that differed from the subject(s). Hawaii depicted other virtual riders, which resulted in subjects reporting these effects such as S01 “Did make it a bit difficult when I saw other riders coasting; I felt I should be coasting; affected my speed”, in addition this caused them to reduce their pace, and broke their level of immersion. One subject even compared how there was a marked difference between the two scenes surrounding these visual cues and their affects, with S20 stating “I did notice one thing in Hawaii when people coast downhill I was pedaling … In Amsterdam I’m still pedaling and this is less dizzying to me”.

One aspect of the scenes, that was only present with Hawaii, was the virtual depiction of “going downhill”. Amsterdam was a level/flat virtual environment. Subjects reported negative physical and emotional responses such as S08 “I’m starting to - my body is telling me I’m going downhill on sections even though I know I’m not; kind of freaky” and S22 “Weird going downhill; pedaling downhill speed thing was weird;...”. Conversely, S19 expressed breaks in immersion “Going downhill and the guy in front of me not pedaling so it’s kind of like "why am I pedaling?". In addition, S19 also reported a positive emotional response “Also going downhill, I really like that”. Other negative physical responses, and breaks in immersion were reported by

S15 “I feel I’m pedaling faster than I should be in the video - it just feels off” and S19 “I felt I was pedaling faster than he was, it felt odd...”

Overall, the reported negative emotional and physical responses correlated with scene content in which the subject’s physical activity (i.e. pedaling) did not align with the visual depiction of the scene, such as when the rider in the VE stopped, but the subject continued pedaling.

Control within VE

The aspect of control was raised on both scenes, specifically surrounding an inability to control the speed of the virtual environment, and also the inability to change direction in the virtual environment. This lack of control only elicited negative physical and/or emotional responses, with no positive responses from any subject in either environment. Again, the Hawaii environment had fewer depictions of stopping, as opposed to Amsterdam; this showed a perceived difference in the subjects related to speed control. Speed control surrounded two aspects - the ability to speed up or slow down, and the ability to control when stops occurred.

Subjects’ remarks related to controlling speed decreases and/or increases, were more pronounced in the Hawaii scene. S08 said “As the rider in front goes further ahead I want to pedal faster, when he gets close I want to slow down as if I am going to hit him”. S11 stated “A way to adjust the way you pedal would affect the way you interact in video”, and S07 said, “[The thing that matters to me is to] also control how fast I’m going”.

For Amsterdam, the speed control focused more on stopping and starting in the virtual environment, but some subjects reported a desire to control speed such as when S21 stated "The speed change is weird since we're not actually controlling speed". The inability to control stopping resulted in S24 stating "Ya crossing the street and waiting for a car is weird. The fact I can't control that". A detailed response from S27 said "I didn't like stopping…to go across the street even though [it is] more realistic; I wish I could have the choice of stopping; not having [the] option [to stop] continued to make me feel more nauseous."

The second aspect of control that emerged related to the ability to change direction within the virtual environment. This was coupled with an increased level of curiosity from one subject, in which they expressed a desire to explore the environment. This was seen in Amsterdam with S02 stating "...I can't turn my bike on this scene but there were some paths, [I would like to] pick a different path to go down". The majority of direction control comments were related to Hawaii, which contained a greater number of long sweeping turns. Amsterdam consisted of fewer turns, when compared to Hawaii, but the turns in Amsterdam were short and sharp. Subjects in the Hawaii VE reported accompanying negative emotional and physical responses as seen with S15; "I got to the first turn, felt I should be turning with it but I'm not". However, this was also seen regarding Amsterdam - S23 "Biking and not being able to control what you're doing with other people around gives me a lot of anxiety".

Complexity and variety upon perceived response

The complexity of a scene relates to the "amount" of objects within the virtual environment, whereas the variety of a scene relates to the differences in objects and content within the virtual environment.

Hawaii did not contain a high level of complexity, nor a high level of variety, with the scene largely displaying winding roads traversing a green mountain landscape. Throughout the scene, the only real changes were when the rider encountered vehicles (either passing, or approaching) within the VE.

Amsterdam contained a higher degree of both complexity and variety, with the scene containing pedestrians, parked and moving cars, trams, buildings, a park, trees, birds, etc.

This higher degree of scene complexity resulted in emerging trends in the data, such as both positive and negative emotional responses and subjects' expectations not being met. It also affected the level of immersion and the ability for subjects to reach a level of presence within the VEs.

One of the surprising and unexpected aspects that can be found in the data, is that subjects derived expectations about each VE from very little actual data. Each subject was informed that a "countryside" setting in Hawaii would be one of the scenes. This small piece of information resulted in a number of subjects reporting that the scene didn't match up to their preconceived expectations. For example, S2 stated, "More sunshine, palm trees…" and S3 stated, "When I think about Hawaii I think about lush plants, beach, water…". S20 stated "Add a beach sometimes… [I] didn't see the ocean". Conversely, Amsterdam resulted in fewer instances where the expectations of subjects were not met. S1 said "[I] was not expecting cars in the environment". However, in one instance the scene met S5's expectations "it's what I expected out of the city".

Regarding variety, Hawaii centered on the fact that the scene was “basic” (S06), “not much to look at” (S31), “I wasn’t motivated by the scenery because it was too basic” (S01) and “Kind of weird just around the mountain; expected to see more scenery” (S24).

Amsterdam, in contrast, resulted in subjects reporting positive emotional responses due to the variety and the resultant complexity within the scene. Nine responses out of the 29 related to variety of the scene were positive emotional responses, with comments like “I liked the city, the shop windows and the side views of the canal” (S03) and “I liked there was a lot to look at - cars, other people, dogs, lots of shops” (S16). This was also accompanied by nine responses that were classed as the subject attaining presence within the scene. None of the subjects reported that the variety of the scene broke their immersion in the experience. There were reports that the variety also caused distraction from the task, which may be the reason for greater levels of immersion and even presence.

Completion of tasks and goals

Of the 31 subjects in the study, a total of 8 (25.8%) subjects terminated the study before it could be completed across both scenes. Hawaii saw 3 (9.68%) terminations, whereas Amsterdam saw 7 (22.60%) terminations. The total number of scene terminations was 10 (16.12%) out of all 62 scenes (31 Hawaii, 31 Amsterdam), across the 8 subjects, meaning some subjects could not complete the task in either VE. Only 2 (6.45%) subjects could not complete both scenes.

In all cases where a subject terminated the study, it was due to negative physical responses, with one instance directly related to "...technical difficulties" (S26) with the display and HMD.

Despite the fact that subjects terminated in both scenes, over double the number of subjects terminated within the Amsterdam scene. Timings for when a subject terminated varied, with S32 terminating at ~30 seconds all the way up to ~7 minutes 48 seconds for S15. The primary reasons for terminating the Amsterdam scene, cited by subjects, were related to scenery complexity, the repeated "stopping in the scene" (S02), the lack of clarity in the display and the quick changes in direction. The only difference between the two VEs was the visual content aspect, and the subjects' perceived responses of Hawaii resulted in a more relaxed emotional response and a lower incidence of negative physical responses. However, each virtual environment was experienced in the same order – Hawaii followed by Amsterdam (i.e. not randomized). Therefore, it is possible that these responses may be due to the total amount of time spent within the virtual environments.

5. Conclusion

I set out to show that changing between different virtual environments can impact users' perceived responses. Perceived responses included visual cues, the perception of control, emotional and physical responses, and task completion. To understand perceived responses, I collected qualitative feedback from surveys, interviews, and user observation between two different virtual cycling experiences. My results indicate that scenery changes within virtual environments of similar experiences impacts the overall perceived responses of users and leads to various negative and positive responses based upon these differences.

Going forward, researchers may want to focus on three main areas: display settings, control, and scene variety.

Display settings pertain to modifying the settings of the display in various ways (such as visual fidelity, frame rates, color hues/saturations, etc.) across the same scenes and different scenes. This would be randomized to determine if any one of these display setting changes results in similar emotional or physical responses as seen during this study.

User control is another aspect that resulted in emotional and/or physical responses from subjects. Studying the same, or different scenes, where control mechanisms are made available, or restricted, could determine if the responses seen in this study were directly related to the lack of control over the VE.

Scene variety (i.e. whether the scene is basic with limited scenery, or complex with a high degree of content types and changes) could also be the focus of a future study. It would be interesting to discover if simply modifying the complexity of scenes, either the same scene or different scenes with different levels of complexity, would result in increased or decreased perceived responses from subjects.

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