An Investigation into Factors influencing Immersion in Interactive Virtual Reality Environments

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Abstract

Two interactive virtual reality environments were used to identify factors that may affect, or be affected by, the degree of immersion in a virtual world. In particular, the level of stress in a "swimming with dolphins" simulation is measured, as is the degree of simulator sickness resulting form a virtual roller coaster.

Analysis of the results indicates that a relationship between the degree of immersion and the following factors: excitement, comfort, quality and age. The following factors are found to depend on the degree of immersion: simulator sickness, control, excitement and desire to repeat the experience.

Introduction

A new computer interaction paradigm has been introduced in the form of virtual reality whereby an individual no longer simply observes images on the computer screen but becomes actively involved in a three-dimensional virtual world incorporating sound and motion. The integration of various input and display technologies gives the user a sense of presence or *immersion* in the virtual environment. Immersion in modern virtual environments requires the use of sophisticated peripherals, such as Head Mounted Displays (HMD), data-gloves and position trackers to provide sensory information and measure the user's response. Effective immersion requires control of many additional factors, both external and internal to the virtual reality. This paper describes two experiments that identify a number of the factors that affect the immersive experience.

The goals of the experiments are twofold: to identify the factors affecting immersion, and to determine the effect of immersion on stress and simulator sickness.

These experiments were run over a period of 9 days at a local science festival. Over 1500 people were taken through two virtual environments during this time. Various physical responses were measured and a number of the subjects were asked to complete questionnaires on various aspects of their experience.

The two virtual environments used comprise an underwater simulation (Figure 1), allowing

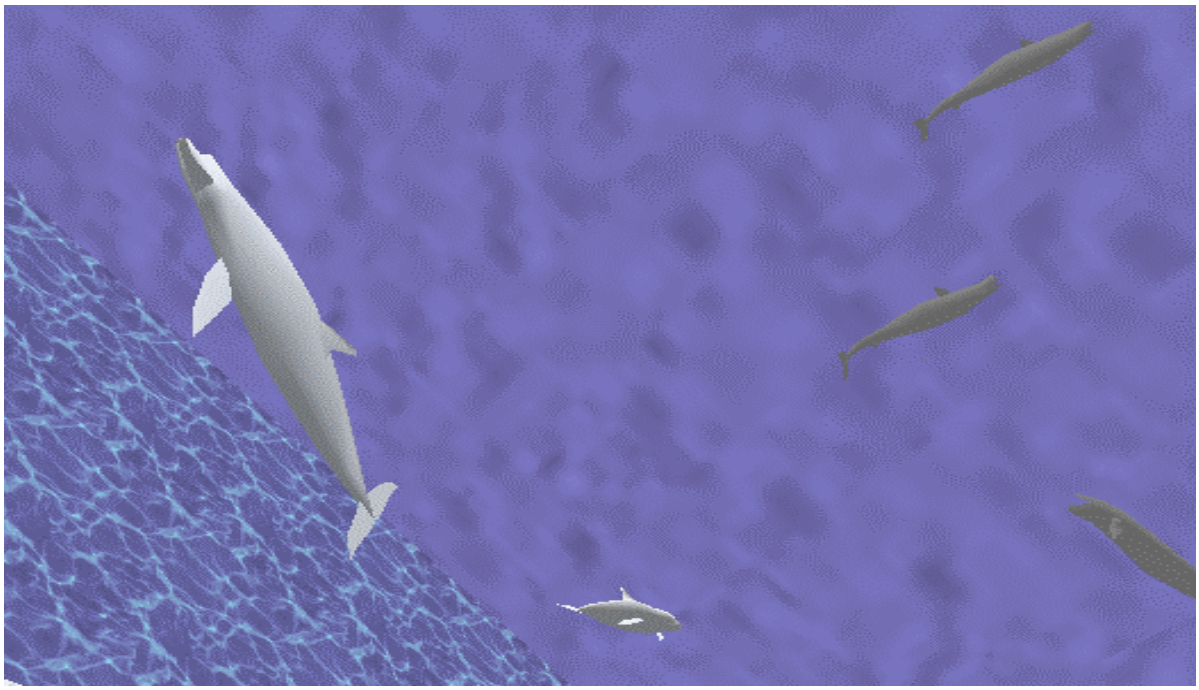

Figure 1: View of the "swimming with dolphins" application

the user to mingle with a range of marine mammals; and a virtual roller coaster (Figure 2), which allows the user to experience a ride around a convoluted track. Both environments are derived from freely available third party code , and have been extended to run on a Head Mounted Display, with head tracking, using the CoRgi Toolkit . Sound effects have also been added.
The questionnaires associated with each experiment are customized to the experiment, but contain a number of questions in common. In particular, previous exposure to virtual reality, excitement, control and immersion are assessed in all cases.

The effect of immersion on stress levels

Stress is the result of a chemical neurotransmitter, norepinephrine, which is released from the brain during stressful situations and acts on the sympathetic nervous system. This causes an increase in contractility of the heart and stimulates or accelerates pacemaker activity and sinoatrial activity . There are many ways to overcome stress but one idea is to enable an individual to experience the immersive effects of virtual reality in an environment that is calm and relaxing. The “swimming with dolphins” experience is intended to reduce the stress levels that the person may be feeling, and thus should have a corresponding effect on the heart rate. Related research has been conducted on similar medical phenomena such as the curing of phobias, helping burn victims overcome pain, Parkinson’s disease and eating disorders through the use of virtual reality .

The effect of immersion on simulator sickness

Simulator sickness is one of the most often mentioned ill effects associated with virtual reality and other immersive environments. Symptoms experienced include nausea, disorientation, eye-strain and headaches. These effects have been observed in simple interactive environments, such as computer games and flight simulators. The effect of immersion can only be expected to amplify these effects.

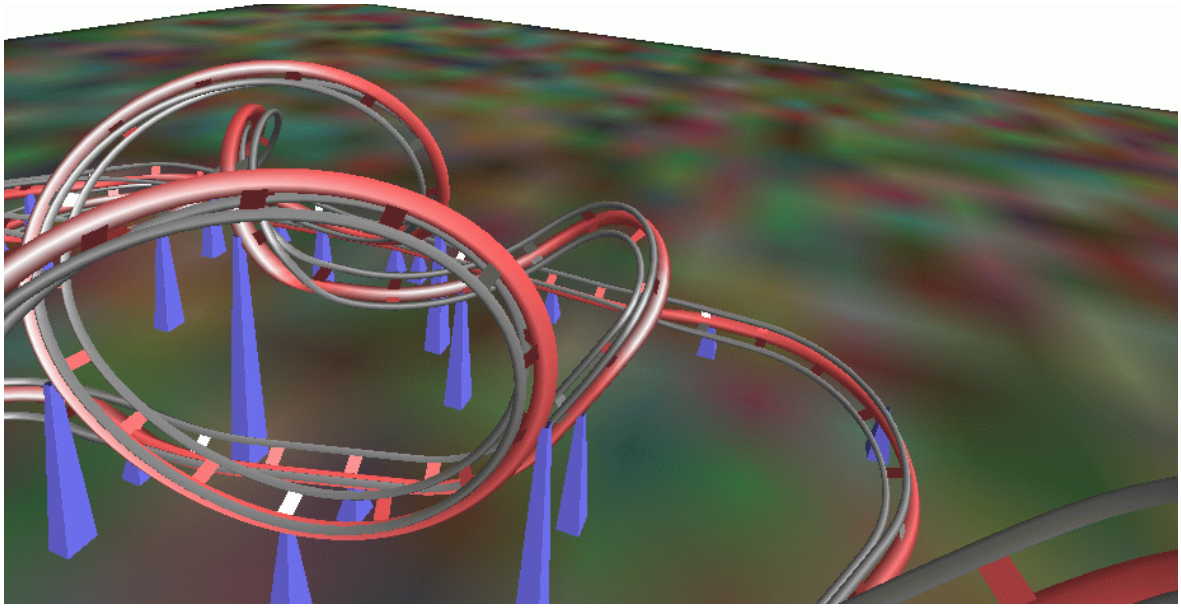

Figure 2: View of the "virtual roller coaster" application

A number of studies have examined simulator and simulator sickness in great detail, and identified a number of potential causes. This investigation concentrates on the effects of cue conflict between the vestibular system and visual system, resulting from the disparity between apparent movement in the virtual environment, and that experienced in physical reality.

The roller coaster environment is chosen specifically for that purpose. Frequent movement of the viewpoint occurs, while the user is seated in a stationary environment.

Purpose

Each experiment shares the common goals of identifying the factors upon which the effectiveness of immersion is dependent. While many factors have been identified previously, such experiments have often used a limited sample size, and been conducted with simple approximations of virtual reality . In this paper, factors that potentially influence immersion such as age and gender, as well as anticipatory excitement, comfort of the environment and impression of control are assessed in detail using interactive virtual environments.

Swimming with dolphins

The “Swimming with dolphins” experience is intended to immerse the subject into a calm and tranquil environment which will allow the subject to feel relaxed and, in theory, reduce any stress they might be feeling. The purpose of this experiment is to monitor heart rate to see what changes occur during the demonstration and to see if it can somehow reduce heart rate which will in turn reduce stress levels.

The reason dolphins have been chosen as the focus of the environment is that dolphins are known to have a healing effect on humans. The Human Dolphin Therapy Center in Miami, Florida has proof of this . An eight-year-old British boy, Nikki Brice, who was starved of oxygen at birth and was left unable to speak, spoke his first words after a few days at the therapy center.

Potential factors related to stress levels are:

1. Heart rate. Heart rate changes are used as an indication of stress levels.
2. Excitement in anticipation of the experience. This influences the initial heart rate, prior to the experience.

Virtual roller coaster

The “Virtual roller coaster” environment focuses on examining the amount of simulator sickness in a virtual environment. Potential factors influencing simulator sickness are:

3. Nervous excitement in anticipation of the experience. This is assessed by the questionnaire; and is relevant given the popularity of the experiment; the length of time spent queuing in order to participate, and the average age of the subjects.
4. Rapid orientation changes in the viewpoint. This is constant and identical for each ride, but a potential variable for future study.
5. Amount of head movement during the virtual ride. A relationship was noticed in one of the test subjects while building the application. It is of interest to determine if this is of more general applicability.

Methods

Both experiments shared a common venue: an isolated room, equipped with a swivel chair and the required hardware (HMD and motion trackers). Subjects queued at the entrance to this room; a front area advertising the experiment as a theme park, and providing some descriptions of the nature of the experiments.

Swimming with dolphins

This experiment is conducted using the *Head Mounted Display (HMD*) through which the subject views the dolphins and a *heart watch* to monitor heart rate. The subject's heart rate is monitored while filling out the first few questions of the questionnaire to obtain a reference heart rate to compare with later results. The subject then “swims” with the dolphins for two minutes and heart rate samples are taken every 15 seconds using a heart watch to monitor the changes that occur throughout the experiment. The subject can move his/her head around to follow a dolphin as it swims past or simply turn to see different animals.

After two minutes the heart monitor is taken off and the subject fills out the rest of the questionnaire thereby quantifying the experience.

The behaviour of the dolphins has been modified to include a degree of curiosity about the diver. This ensures that the dolphins spend a portion of their time in the vicinity of the diver. A herd of whales is also present, using a simple flocking algorithm to encourage them to remain as a group.

Virtual roller coaster

The position of the user in the virtual environment is fixed relative to one of the carts. The user is free to turn his/her head, which changes the view presented. The questionnaire for the roller coaster includes questions that relate to the tendency to experience motion related nausea, as well as asking about the discomfort actually experienced. In addition, the data from the head tracker is logged for later comparison.

The experiment runs for two complete laps of the roller coaster track. This allows the subject time to get used to the simulation, while remaining short enough to prevent excessive repetition and boredom.

Table 1: Summary of results obtained from the dolphin questionnaire

	Result	Range
Sex:	Male: 205 Female: 141 Missing: 9	
Age:	Mean: 17	6-64
Previous experience of VR:	No: 286 Yes: 68 Missing: 1	
Level of anxiety before experience:	Mean: 3.6	1-5 (5=totally relaxed)
Expectations:	Mean: 2.1	1-5 (1=excited)
Comfort:	Means: 2.6,2.4,2.5 (HMD, Seat, Environment)	1-5 (1=comfortable)
Effectiveness of immersion:	Mean: 3.4 Mode: 3	1-5 (1=immersed)
Control:	Mean: 2.9	1-5 (5=total control)
Level of anxiety after experience:	Mean: 3.8	1-5 (5=totally relaxed)
Excitement:	Mean: 2.8	1-5 (1=exciting)
Desire to repeat the experience:	No: 31 Yes: 233 Missing: 91	
Mean Heart Rate:	Mean: 82.21	57-113
Change in Heart Rate:	Mean: -0.09	-59-46
Reference Heart Rate:	Mean: 81.48	39-131

Results

Swimming with dolphins

A total of 355 questionnaires were collected and of those, 82 contain data regarding heart rate changes. A number of interesting observations are made, and the results are summarized in Table 1.

Heart rate

Figure 3 shows the heart rates of four subjects, typical of the different categories of result. In general the data indicates that the initial heart rate is elevated when the demonstration begins. This could be attributed to the fact that most individuals are excited and anxious about seeing this demonstration and therefore have an increased heart rate. Most of the subjects' results show a decline as the demonstration progresses but there were exceptions as can be seen where the heart rate slowly increased throughout the experience. This could also be excitement as the majority of subjects are young scholars.

From the information gathered, the excitement of the experience is independent of the change in heart rate at the beginning of the experiment and at the conclusion. The heart rate may have changed during the experience but the overall excitement of the experience does not have any effect on the change of the heart rate. The results do show, however, that the majority of subjects do experience a drop in heart rate as the experiment progresses, and hence some stress relief.

The degree of immersion

The result of comparing immersion and control shows that the amount of control the subject feels he/she has is dependent on the degree of immersion they feel. If the subject feels totally immersed in the experience then he/she feels that they have substantial control. Those individuals who feel that they have no control do not feel immersed in the experience.

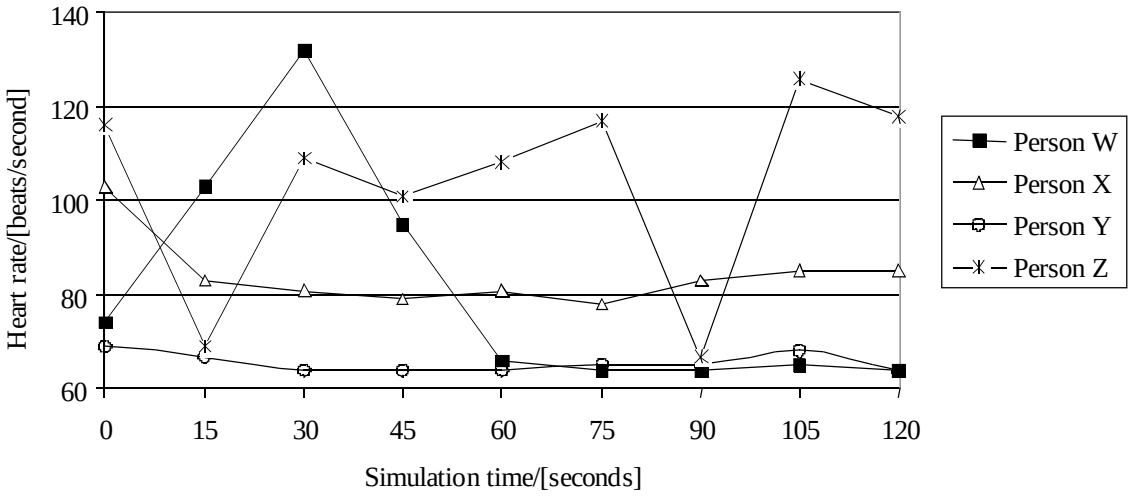

Figure 3: Four sample heart rate measurements

Comparison of immersion and excitement yields similar results, with the majority of the subjects providing identical values for both.

Expectations before and after

The responses from the questionnaires indicate that many of the subjects have never seen virtual reality before, so it is new and exciting for them. Their expectations are, in general, high before the experiment. After the experiment, however, their ratings for the experience range between exciting and not particularly exciting. This could be attributed to the fact that many people have been on simulated rides, which they interpret as being virtual reality. These rides are far more realistic and exciting but lack the interactive element essential in virtual reality. Another contributing factor could be the expectations of virtual reality after films such as *The Lawnmower Man.*

Anxiety before and after

The perceived stress levels before and after the experiment are in general unchanged. If individuals are relaxed before the experiment they are relaxed afterwards too. Most of the subjects who are tense before the experiment are still tense after the experiment but some are able to relax.

Virtual roller coaster

From the approximately 750 people who experienced the roller coaster, a sample of 143 completed questionnaires was collected. The results obtained are summarized in Table 2.
The degree of immersion experienced by the participants is related to a number of other factors measured. In particular, factors such as the excitement of the experience and the comfort of the peripherals, and physical environment during the ride are closely related to the amount of immersion experienced. The amount of immersion experienced determines the success of the ride, with those who are unwilling to repeat the experience giving a low rating to immersion.

Table 2: Summary of results obtained from the roller coaster questionnaire

	Result	Range
Sex:	Male: 63 Female: 80	
Age:	Mean: 18	5-54
Previous experience of VR:	No: 108 Yes: 35	
Tendency to simulator sickness:	Mean: 4.3	1-5 (5=never)
Expectations:	Mean: 2.1	1-5 (1=excited)
Comfort:	Means: 2.5, 2.4, 2.5 (HMD, Seat, Environment)	1-5 (1=comfortable)
Effectiveness of immersion:	Mean: 3.4 Mode: 4	1-5 (1=immersed)
Control:	Mean: 2.3	1-5 (1=total control)
Simulator sickness experienced:	Mean: 4.9	1-5 (5=no effect)
Amount of head movement:	Mean: 1.7	1-3 (1=no movement)
Excitement:	Mean: 3.0	1-5 (5=exciting)
Desire to repeat experience:	No: 27 Yes: 116	
Total head movement:	Mean: 693.6°	355.6°-2036.4°
Head movement for the first loop:	Mean: 7.68°/s	3.86°/s-18.44°/s
Head movement for the second loop:	Mean: 7.54°/s	3.50°/s-26.24°/s

Head Movement

The amount of head movement during the ride is relatively low. Four sample sets of measurements over a portion of the ride are shown in Figure 4. These illustrate a range of measurements from an active subject, to some that are virtually comatose. Most subjects show a cumulative head rotation for the entire ride of less than 800°. Only 5 subjects recorded head rotation of more than 1200°. This value is measured over the 90 second duration of the ride, and includes over 1000 samples from the motion tracker. Slight motion of the head and noise in the tracker data (typically about 0.5° per sample) accounts for a large portion of this value. This contrasts severely with the perceived amount of head movement, where the amount of motion perceived is independent of values actually measured. Many of the subjects feel that they are making more head movements than is actually the case.

The sole correlation with measured head movement occurs with the comfort level of the HMD. The most adventurous subjects, with the most head motion, find the head mounted display to be very comfortable.

As may be seen from the results in Table 2, head movement decreases during the second lap around the track. The majority of the subjects stop reacting to the simulation by that stage. The upper bounds, on the other hand, increase on the second lap. Those subjects who have identified the reactive nature of the simulation continue to make increased use of the facility.

Simulator Sickness

The amount of simulator sickness experienced during the ride is minimal. Few subjects report any tendency to simulator sickness, and even less report feeling any ill effects after the simulation. Due to the nature of the demonstration, subjects are warned of the potential risk. This may eliminate many who may be prone to such effects. Of those candidates who did experience simulator sickness (about 12), their level of immersion is assigned a rating at least as high at that given to the degree to which the effects are felt. This would indicate that a greater degree of immersion is required before any simulator sickness effects will be significant. Similar results are obtained when comparing simulator sickness and the

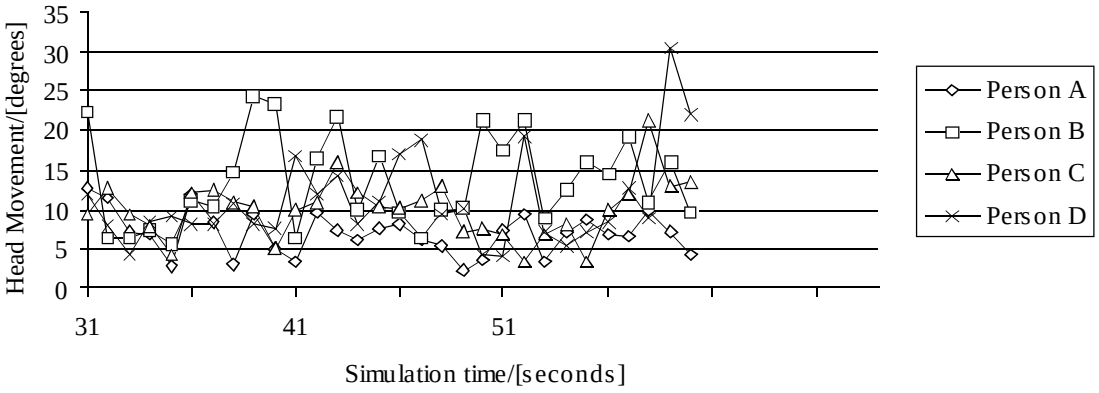

Figure 4: Four sample head motion measurements

excitement of the experience.
Those experiencing simulator sickness tend to move their heads less than other subjects do. This may suggest that those experiencing ill effects are assuming that head motion is aggravating the condition. This result needs to be examined in more detail in future experiments, in which head motion can be controlled as an independent variable.

Age

The range of ages sampled show an interesting trend. Since most of the participants are of school going age, the data shows a large peak between the ages of 10 and 20. A smaller peak occurs at ages between 35 and 45, presumably the age group of most parents and teachers. This older group tends to provide lower scores for immersion and excitement consistently. Also this group feel that they have greater control over the environment, while not showing any significant difference when comparing the relative amount of head movement. The issue of control is discussed in greater detail in the next section.

Relationship between the two experiments

Most participants react quite favourably to the demonstration, and indicate their willingness to repeat the experience. Few do repeat the experience however, an effect possibly due to the popularity of the exhibit and the corresponding queues. Many commented on the realism of the graphics and sounds. Some indicated in quite emphatic terms that these were not of the standard expected of virtual reality systems. The images used are built from smoothed and shaded polyhedral objects, with minimal use of the texture mapping prevalent in many of the commercial simulators. The sequences are rendered at >20 frames/second by a Silicon Graphics O2.

While many of the values in common to both sets of questionnaires yield comparable results, there are some categories in which the results differ between the two virtual environments provided. In particular, the values provided for immersion, control and excitement differ between the two sets of experimental data.

Excitement and Immersion

The "Swimming with dolphins" environment is rated as providing both a more immersive experience, and one which is more exciting. Given that a relationship between these two factors has been established, it remains to hypothesize as to which factors are responsible for the difference between the two environments. Possible explanations are:

6. The underwater world encourages looking around, emphasizing the three dimensional nature of the environment.
7. The underwater environment responds only to the user's movements, emphasizing the interactive nature of the world. Movement of the user in the roller coaster simulation is insignificant compared to the overall motion of the cart.
8. The differences in the nature of the demonstration may encourage greater user empathy with the one as opposed to the other.

Further experimentation is required to investigate these possibilities in greater detail.

Control

The values produced relating to control of the virtual world yield completely unexpected results. The roller coaster demonstration in which one is dragged around a preset course is rated as allowing greater control than the "swimming with dolphins" in which the users' control of their viewpoint is central to effectively experiencing the environment.

The meaning of control in a virtual environment from the point of view of the layman is one that requires further investigation. While the values in the samples taken show some correlation with the amount of head movement (both reported and measured), the difference between the values reported for users with and without previous experience of virtual reality is more significant. Those with previous experience of virtual reality experiences tend to report little control, while those receiving their first virtual reality experience acknowledge that they have at least a moderate amount of control. The authors tend to attribute this to the availability of so-called virtual reality rides, which provide a view of a virtual environment, without actually allowing any user interaction. Another hypothesis is that control is associated with translational motion (used in the roller coaster), as opposed to rotational motion used to control the viewpoint in both experiments.

Conclusions

The following factors have been found to influence the effectiveness of immersion in a virtual reality environment:

9. Excitement of the experience.
10. Comfort of peripherals and environment during the experience.
11. Quality of the sound and images.
12. Age.

The following factors have been found to show a dependence on the degree of immersion:

13. Simulator sickness.
14. Control.
15. Excitement of the experience.
16. Desire to repeat the experience.

The sample was taken at a school science festival, frequented in the most part by children of school going age. This will have some effect of the accuracy and generality of the results. Some of the relationships between values measured may be influenced by lack of

understanding by the layman of the meaning of the terms involved.

Future work

Further experiments are planned to resolve the issues raised in this study. In particular, the following will be addressed:

17. Improvement in the perceived realism of the environment, including the use of stereoscopic views through the HMD.
18. The meaning of control in a virtual environment.
19. The nature of the link between the level of immersion and the excitement of the experience.
20. A comparison between interactive and non-interactive environments.

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