How Deep Is a Virtual Reality Experience? Virtual Environments, Emotions and Physiological Measures

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Abstract. Previous studies have shown a relationship between virtual environments and subjectively evaluated emotions. The present study intends to understand if an emotion evaluated subjectively is related to an objective measurement like heart rate. In the study, a design between subjects with two virtual environments was used. A sample of 58 participants participated in this study, in two immersive virtual environments: Helix® (a roller coaster experience, n = 36); and Yana® (experience of sunset/sunrise, n = 22). Subjective and objective measures (heart rate) were measured. The results are consistent with previous studies and our hypotheses. As for the subjective measures it is concluded that these measures were related to physiological measures, so the emotional response to an event in virtual reality is not only an interpretation of the situation but also a physiological phenomenon.

Keywords: Virtual reality (VR) · Immersive virtual environments (IVEs) · Emotions · Heart rate · User experience (UX) · Physiological measures

1 Introduction

The results of our previous study [1] demonstrated that the Self-Assessment Manikin (SAM) was adequate to discriminate the emotional dimensions (Valence, Arousal and Dominance) and that the used questionnaire was sufficiently refined so that in its results we can observe the expected relationships between the subjective measures collected and the different Immersive Virtual Environments (IVEs) analyzed. However, some doubts have arisen: will those subjective measures be a mere response to a situation, or they have also a physiological answer?

Most of the studies evaluate the emotional reactions from questionnaires that are carried out after the exposure to the stimulus of the IVEs [1–8]. But with the application of the questionnaire only after the experience, it is not possible to access an evaluation while the participant is immersed in the virtual environment.

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It is also possible for the researcher to ask questions to the participant while he/she is using a Head-Mounted Display (HMD), as described by Men [8], however if the researcher poses any question, he will break the sense of virtual presence of the participant [7]. Ideally, there should be no interaction between the participant and the researcher during RV interaction.

Some studies integrate subjective experience questionnaires directly in virtual reality environments [9] thinking that in this way they minimize the break in sense of presence. However, physiological measures such as Heart Rate (HR) can be measured during exposure to the stimulus, without intrusiveness, since the cardio-frequency meter is a band that is placed on the wrist, similar to a watch.

Some studies have sought to correlate the presence with electrophysiological measures such as HR, respiration rate, skin resistance and peripheral skin temperature. Despite the results of HR and skin temperature did not prove to be good measures of presence and results of their correlation with presence were inconclusive [10].

The literature states that the Arousal is a particularly strong indicator of emotional involvement. Arousing emotions should lead to higher presence ratings and correlate more closely with presence ratings, than calm or serene emotional states [1–3]; for a review see Diemer [11].

Other studies reveal that higher HR and Electrodermal Activity (EDA) are correlated with physiological arousal and as such with some of the influencing factors associated with user Quality of Experience (QoE) [12].

This study was proposed to evaluate the subjective emotional (valence, arousal and dominance) and heart rate responses, when the participants interact with two immersive Virtual Reality (VR) environments. A between subject design was used with two virtual environments.

In this study, we chose the IVEs Yana® and Helix® because in the previous study [1] they were shown to be opposites in the Arousal and Dominance dimensions. In the Yana® participants generally reported having relaxed during the experience, and in the end said to feel calmer.

We intended to prove if there are significant differences in HR between control state (rest) and experience IVE (Yana®/Helix®), and if this is related to subjective measures analyzed. These results intend to bring robustness to the use of HR measures as an indicator in deeper assess of User Experience (UX) in IVEs.

2 Methodology

2.1 Sample

In Lisbon during a public event named Futuralia 2017, we have recruited our convenience sample. Futuralia is the largest education and training fair in Portugal. For three days in Futuralia we recruited 58 participants of which 30 women and 28 males. The average of age was 20.91 years, with 8.78 years of std. deviation. The minimum age was 14 years and the maximum of 58 years.

We randomly divided participants into 2 groups.

In the first group 22 participants (55% Female, 45% Male) experienced the YANA® IVE. This group showed an average age of 18.86 and std. deviation of 3,67 years;

In the second group 36 participants (49% Female, 51% Male) experienced Helix® IVE (Virtual Roller Coaster). This group showed an average of 22.17 years and 10.65 years of standard deviation.

Participants were asked about the existence of any antecedent in relation to epileptic manifestations, or eventual cardiac pathologies. All participants denied.

Women were asked about the existence of pregnancy. When the answer was positive, for safety reasons, we did not grant the Virtual Reality experience.

Thus, all pregnant women or persons with episodes of epilepsy, or with cardiac pathologies were excluded from participating in this study.

2.2 Immersive Virtual Environments

The two IVEs that were most opposed in the results of our first study [1] were chosen. The first IVE was Yana® Virtual Relaxation, a paradisiac beach developed by The Campfire Union Inc:

Description: In the IVE YANA, the user enjoys a sunset and sunrise on a paradisiacal beach. The user is in the center of the beach and glimpses in the middle of the sea a rock formation that is reflected in the calm waters of the sea (Fig. 1). After the sun goes down, it takes place at night time (Fig. 2). During the night time the sky fills with stars forming constellations. Falling stars paint the sky.

On the horizon line a boat appears sailing parallel to the beach. The sound environment is made up of sounds of seagulls, birds, Tibetan bowls, bells and sea waves.

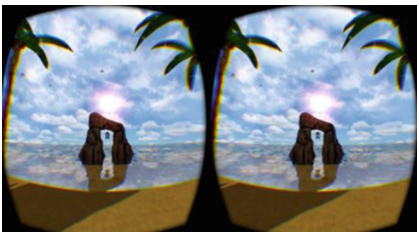

Fig. 1. Detail: begin IVE YANA®

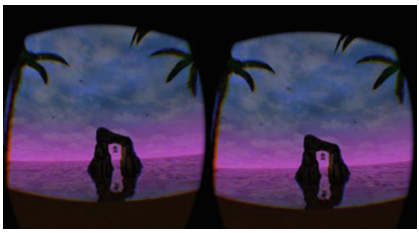

Fig. 2. Detail: begin of the night IVE YANA®

This environment was chosen because in the results of our previous study [1] it was shown that it had the lowest values of Arousal.

The second IVE Helix® is a virtual roller coaster experience: Helix® Roller Coaster VR, was developed by Archivision®.

Description: When the Ive Helix starts, the user is sitting in a roller coaster chair. The other chairs beside him (Fig. 3) and behind him are occupied with virtual avatars. The

electronic music and the enthusiastic cries of the avatars create the sound environment. The ride begins (Fig. 4), during the roller coaster ride the user experiences, climbs, descents and loopings.

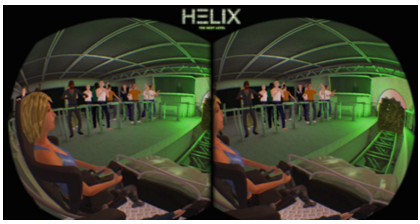

Fig. 3. Begin of IVE Helix®

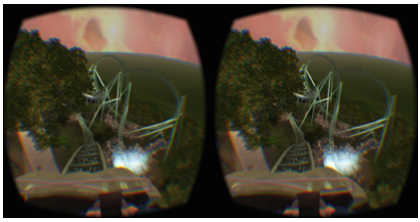

Fig. 4. Detail: begin of the slope, IVE Helix®

This IVE was chosen because in the results of our first study [1] it was shown to have the highest Arousal values.

2.3 Measures and Analysis

Independent samples were used, and the manipulated variable was IVE (Yana® and Helix®). The subjective dependent variables were emotional dimensions, arousal, valence, domain. The objective dependent variable was HR.

It is common to investigate the presence and the emotional experience from the correlation between these measures [1, 4, 6] mainly in the literature on the exposure to VR [13–18].

The participants sat down in a chair, the heart rate monitor was placed on his wrist. The heart rate was measured for 4 min (it will serve as control when compared to heart rate measurements during IVE exposure).

The exposure to the IVE Yana was approximately 8 min, and the exposure to IVE Helix was approximately 4 min.

Before experiencing IVE, all participants answered the first part of the questionnaire. At the end of the IVE, the participants answered the second part of the questionnaire (Fig. 5).

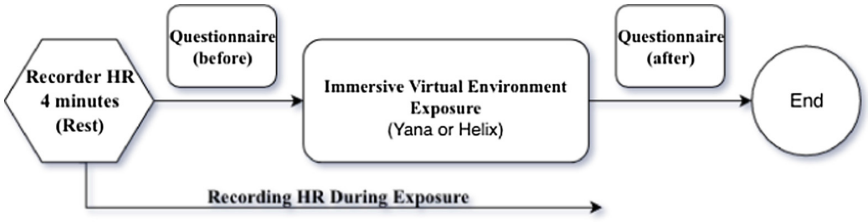

Fig. 5. Research moments diagram

2.4 Objectives

The main objective was to verify if the physiological indicator heart rate is related to the arousal levels of the participants in a virtual reality experience.

The specific objectives were to recognize associations between different virtual environments and: Emotional dimensions: Valence, Arousal, Dominance; Heart Rate; To identify whether an exciting experience such a virtual roller coaster (helix) experience induces an increase in Heart Rate mode; To identify if a relaxing experience like watching the sunset on a virtual beach induces a decrease in Heart Rate mode.

2.5 Procedures

Volunteers of the degree in Ergonomics of the Faculty of Human Kinetics of Universidade de Lisboa helped us during the experimental periods. They organized the participants and registered the values of subjective measures reported by them.

All participants, after reading the informed consent form and clarifying some doubts, agreed to participate in the study in exchange for experiencing IVE with a head mounted display (HMD).

The content of the IVE was unknown to all participants; they just knew that it was VR. In this way we assume that the interest in participating was based on the curiosity to use the RV.

IVE was randomly selected and participants only experienced one IVE without previous knowledge of the content.

After reading and accepting the consent form, the participants would move to an ordinary chair, and were asked to place a heart rate monitor on the wrist. From that moment we asked the participant to remain serene sitting in the chair for a period of 4 min in order to record (2 Hz) his heart rate as control measure. During this time, we asked the participants to speak as little as possible.

After recording HR as a control, participants were advised that there were no right or wrong answers to the questionnaire that was to be shown to them. The answers to the questionnaire should be the individual perceptions regarding the issues. All participants were advised that they could leave the experience at any time for any reason that was relevant. The questionnaire was then introduced to the participants. First some sociodemographic questions and then questions about what they expect to feel with the use of VR.

After questionnaire being answered, the researcher assists the participant in comfortably placing the Head-Mounted-Display (HMD). After all, properly adjusted and the sound set by the participant, the participant tells when to start the VR experience.

At this moment the hour, minutes and seconds were recorded, to start recording the HR during the IVE exposure.

At the end of IVE the HR record was interrupted. The researcher helped remove the headphones and then the HMD. The researcher asks if everything is okay. Given the affirmative answer the researcher introduced the second part of the questionnaire, now the participant responds according to the emotional response generated by the IVE.

2.6 Evaluation Questionnaire

We used the questionnaire from our first study [1]. In order to make an evaluation compatible with the objectives of the study and the temporal constraints of this type of events (public event Futuralia 2017), The first part of the questionnaire was applied before the participant used the RV. At this stage it was important to collect some sociodemographic questions that allowed us to later relate the data collected according to gender, age, level of schooling, nationality. Then it was important to gauge the participant's typology and expectation regarding VR. For this there were two questions about prior use, or knowledge of the existence of VR as technology. Two issues concerning the habit of playing FPS (first player shooter). Next, in relation to the expected use of VR, the participants were questioned about the experience they were about to have about valence arousal and dominance with the use of SAM (self-evaluation-manikin); The presence was measured between semantic anchors with 9 degrees of freedom. In the questionnaire, after the VR experience, were applied the same previous measurements.

So, participants were questioned about the sense of Presence, Valence, Arousal and Dominance before and after the IVE. After the IVE we also asked questions relating to the sense of Concentration, Relaxation and Activation during and after the IVE. All the answers were measured with 9 degrees of freedom.

2.7 Hardware

The hardware was constituted by the PC, the display and the Cardio-frequency meter.

Display: As HMD, an Oculus® Rift DK2 was used. The specifications of this HMD are: Display 5.7 in. OLED (PenTile); Resolution 1920 × 1080, 960 × 1080 per eye; Refresh Rate 75 Hz, 72 Hz, 60 Hz; Persistence 2 ms, 3 ms, ful; field of view 100° (nominal); Update Rate 1000 Hz, Positional 60 Hz; Weight 0.97 lbs (440 g);

PC: Alienware® M17x R3 17.3" Intel i7-2670QM 2.20 GHz, 16 GB RAM, 512 GB + 256 GB ssd. NVIDIA GeForce GTX 560 M graphics card;

Cardio-Frequency Meter: Mio® Alpha I, 2 Hz, Max Readable Heart Rate: 220 BPM, Min Readable Heart Rate: 30 BPM;

3 Results

Of the 58 participants, 31% said they had already experienced virtual reality at least once. All the participants affirmed at the end of the IVE use that it was the first time that they had been in that IVE.

Table 1 shows the values of the mean and standard deviation of the subjective measures (Arousal, Valence, Dominance; Presence) before experiencing IVE, and after experiencing IVE.

For a greater control we can also observe the mean and standard deviation of the subjective measures: Concentration (during IVE); Relaxation (during IVE); Relaxation (after IVE); Activation (after IVE).

Still in Table 1, we can observe the objective measure HR with the respective values: mode; median; 10th percentile. For HR analysis we can observe the mean frequency through the mode. With the median, we observed the maximum frequency. Through the 10th percentile, we observe the minimum frequency.

Table 1. Summary of results (subjective and objective measures) obtained in the studied environments.

Variables	Statistics	Yana®		Helix®	
		Before	After	Before	After
Arousal	Average	5.32	2.64	6.28	6.42
	Std. deviation	2.12	2.32	1.81	2.22
Valence	Average	7.14	7.59	6.89	7.78
	Std. deviation	1.28	1.29	1.65	1.33
Dominance	Average	5.41	5.09	4.97	4.69
	Std. deviation	2.42	2.24	2.03	2.60
Presence	Average	7.64	7.18	7.22	7.31
	Std. Deviation	1.33	1.76	1.48	1.79
Concentration (during)	Average		7.64		7.39
	Std. deviation		1.21		1.48
Relaxation (during)	Average		7.86		5.22
	Std. deviation		1.21		2.22
Relaxation (after)	Average		7.41		5.86
	Std. deviation		1.62		2.01
Activation (after)	Average		3.82		6.17
	Std. deviation		1.82		2.02
Heart Rate (control)	Mode	80		83	
	Median	80		84	
	Percentile 10^{th}	67		73	
Heart Rate (during)	Mode		68		83
	Median		75		84
	Percentile 10^{th}		66		71

ANOVA between groups was made. For the Arousal, with a test statistic F = 38,231 corresponds a null p-value, thus it is rejected H0, being able to affirm that there are significant Arousal differences between the two IVEs (Yana/Helix). We also observed significant differences between the two IVEs in the control measures of

Relaxation (during), Relaxation (after) and Activation (after), with the respective test statistics F = 26,306, F = 8,121 and F = 19,869, corresponding all to null p-values. For the other subjective measures, there were no significant differences between the two environments (Yana/Helix).

To better illustrate the results obtained with HR measurement by IVE, between control and during exposure to IVEs, see graphs: HR Mode (Fig. 6), HR Median (Fig. 7), HR 10th Percentile (Fig. 8).

Fig. 6. HR mode: Yana/Helix (control/during)

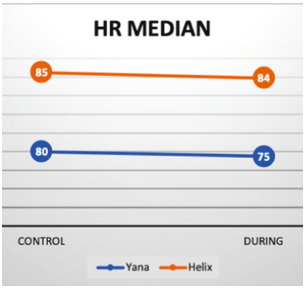

Fig. 7. HR median: Yana/Helix (control/during)

Fig. 8. HR 10th Percentile: Yana/Helix (control/during)

As expected, compared with Yana the values of HR with Helix are always higher.

4 Conclusion

The results obtained were in agreement with our initial hypotheses. Arousal has been shown to have a strong correlation with heart rate. The sample used is a convenience sample recruited at an event called Futuralia. This event is intended for high school finalists, so the participants of our study were essentially secondary school students. Participants before experiencing IVE were mostly very enthusiastic because they were going to experience Virtual Reality. These facts can also be verified by the high Arousal states prior to the IVE trial. This may have influenced the results of no significant differences between the control measurement and the Heart Rate measurement during the roller coaster IVE (Helix).

We also verified significant differences in Activation after the experimentation evoked in YANA and Helix, with helix reported as the highest, accompanied with an average frequency (mode), minimum frequency (10th percentile), and maximum frequency (median) of HR also higher.

In the sunset at the beach (YANA) we find that it induces a state of calm in the participants which is accompanied by a decrease in Heart Rate. This fact reveals once more the relationship of proximity between the Arousal values evoked after the trial of this IVE. It should be noted that the Presence values were lower than in the Helix

environment, however we think that these values are due to the weak perceived realness of the Yana environment when compared to the Helix environment.

These results empirically demonstrate the power of using virtual reality as a modulating instrument for calming and relaxation stages, accompanied by the physiological response of a lower HR. Our results strengthen the development and design of IVEs for stress management and relaxation.

For UX evaluations the HR is a very interesting measure to describe the levels of Arousal during the use of VR products. Further research is needed on this topic.

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