Comparing emotional states induced by 360° videos via head-mounted display and computer screen

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Abstract—In recent years 360° videos have been becoming more popular. For traditional media presentations, e.g., on a computer screen, a wide range of assessment methods are available. Different constructs, such as perceived quality or the induced emotional state of viewers, can be reliably assessed by subjective scales. Many of the subjective methods have only been validated using stimuli presented on a computer screen. This paper is using 360° videos to induce varying emotional states. Videos were presented 1) via a head-mounted display (HMD) and 2) via a traditional computer screen. Furthermore, participants were asked to rate their emotional state 1) in retrospect on the self-assessment manikin scale and 2) continuously on a 2-dimensional arousal-valence plane. In a repeated measures design, all participants (N = 18) used both presentation systems and both rating systems. Results indicate that there is a statistically significant difference in induced presence due to the presentation system. Furthermore, there was no statistically significant difference in ratings gathered with the two presentation systems. Finally, it was found that for arousal measures, a statistically significant difference could be found for the different rating methods, potentially indicating an underestimation of arousal ratings gathered in retrospect for screen presentation. In the future, rating methods such as a 2-dimensional arousal-valence plane could offer the advantage of enabling a reliable measurement of emotional states while being more embedded in the experience itself, enabling a more precise capturing of the emotional states.

Keywords—Affective state, Emotions, 360° Video, Head-mounted display, Rating method

I. INTRODUCTION

There is a steady increase in applications and research using virtual reality. In contrast to well-studied media types like audio, speech, and video, there are many factors related to the experience produced by virtual environments that have not been exhaustively studied. Understanding how people perceive the quality of VR systems is pivotal to improve the Quality of Experience (QoE) of users [1]. Given that QoE is a broad construct, there are many possible influencing factors associated with it. Some of these are of technical nature [2], while others are related to the users’ perception of the system [3]. The present paper will be focused on the latter.

Multiple methods can be used to assess perception. Some of the most common are 1) direct measures (e.g. asking questions) [4], 2) indirect measures (e.g. observing behavior) [5], and 3) psychophysiological signals [6]. Some of the direct approaches have been validated to be used in a paper version or on a screen. However, it is not always clear whether these methods can be used reliably within virtual environments. Recent studies suggest that it is possible to use questionnaires in virtual environments to assess constructs (i.e., presence) [7]. However, it is not clear if the same applies to other constructs, such as emotional states.

Emotions are important in the field of QoE because they are pivotal in the overall experience of users. The methods previously mentioned (direct, indirect, and psychophysiological measures) can be used to estimate the emotional state of people. For example, to analyze how aroused someone is during and after using a product. Pictographic scales are often used to assess arousal (the intensity of an emotion) and valence (how negative or positive an emotion is) [8]. Usually, participants use these scales to rate their emotional state on a sheet of paper or on a computer screen. However, when VR is used for the presentation of stimuli, participants have to leave the virtual environment to give the rating and then enter again to proceed with the test. This breaks the entire experience and might bias the measures.

An additional problem of many methods used to assess the emotional state of participants is that the measure is taken after the actual experience (i.e., in retrospect). There are tools that allow taking measures of perceived quality during the media stimulation (i.e., continuously) [9], but it is not clear if these tools work reliably for emotional states as well. Besides, the measurement method itself and the form of the media presentation can bias the results.

On the other hand, the spread of 360° videos has created an interesting source of media content for HMD/VR systems. Furthermore, it is known that immersive stimuli can lead to a stronger emotional response [10]. However, it is not clear how to assess participants emotional states while watching a 360° video. To the knowledge of the authors, there is no research about the validity of a continuous rating method of emotional states for 360° videos, considering that the immersiveness of the stimuli is a potential influencing factor.

Therefore, the aim of this paper is 1) to investigate if evoked emotions change due to the used presentation system (HMD vs. computer screen), 2) analyze whether there are differences in retrospect vs. continuous measures, 3) to show if the two rating method result measures the underlying construct, and 4) understand how the immersiveness of the stimuli influences the emotional experience, as an overall effect and for both rating methods separately.
A. Objectives

In order to explore the possibility of gathering ratings for emotional responses in virtual reality, a study was designed, giving participants the opportunity to rate their emotional state. The focus of the study was on two main parameters: the presentation system and the rating method. There is already research in the area of immersive environments and emotional responses \([11]\) and how to gather emotional responses in a virtual environment \([12]\). What has gotten less focus is how the difference in the immersive environment affects the emotional responses of the participant. To be able to gather ratings in a virtual environment, \([12]\) proposed to use an emotional grid to measure emotional responses. The comparison of the measured rating showed a high similarity to the measured values outside of HMD. The ratings were gathered in retrospect (i.e., after the stimulus presentation was over), showing the potential of using in HMD measures in general. Differentiation of conditions for the study has been created by using different text lengths (short title, medium, and longer paragraph), as well as different HMD devices with different screen resolutions.

Figure 1: Rating user interface of the continuous rating method. Shown with the background of one exemplary video.

The remaining sections of the present paper explain the methods and results of the study with the aim of answering these questions:

- Were the selected stimuli able to evoke emotional responses (independent from presentations system and rating method)?
- Do the evoked emotions change due to the used presentation system (HMD vs. computer screen) (independently from the rating methods)?
- Do the two rating methods measure the same underlying construct?
- Does the continuous rating have an impact on the experienced presence (independently from the presentation system)?

II. RELATED WORK

Two concepts are pivotal for the study of virtual environments: presence and immersion. Presence is defined as the sense of existing in a virtual environment \([14]\) or as the illusion of being in a real place \([15]\). Early approaches defined immersion as a property of a system strictly related to its technical characteristics (i.e., the ability of the system to generate a realistic environment) \([16]\). In contrast, more recent approaches propose that immersion is also related to the psychological experience of the user \([17]\). Therefore, the classical distinction between presence and immersion has become less clear.

Even though there is not a unified definition of presence, most authors agree that it is a dimensional construct. According to \([18]\), it consists of three dimensions: personal presence (simulation of real-world stimuli in the virtual world), social presence (existence of other people in the virtual world), and environmental presence (the ability of the virtual world to adapt itself to the user). This definition is coherent with other findings, suggesting that presence is strongly related to the subjective experience of the user \([17]\).

The lack of a unified definition of presence makes it more complicated to measure it. However, \([19]\) used a factor analysis to enable a standardized measurement of perceived presence with a subjective scale: the Igroup Presence Questionnaire (IPQ). Other commonly used questionnaires are the Slater-Usoh-Steed (SUS) Questionnaire \([20]\) and the Presence Questionnaire (PQ) \([21]\).

Previous research suggests that there is a correlation with immersion and presence, as well as some suggestions on the correlation between immersion and emotional states. Further findings show that emotional states influence the sense of presence in virtual environments \([22]\) and that more immersive environments produce stronger emotional responses \([11]\). Other authors have investigated the impact of perception and presence on emotional reactions \([23]\) and how the stereoscopy (depth and 3D) influence presence and emotions \([25]\). What is still widely unknown is in which conditions immersion affects emotions and which emotional dimensions it affects.

The assessment of emotional states also depends on the theoretical approach used by the researcher. Some authors propose that emotions are better described in terms of categorical variables \([26]\), while others opt for the usage of continuous variables. An iconic example of the latter can be found in the Circumplex Model of Affect \([27]\), which consists of an orthogonal space with two dimensions: arousal and valence. Consequently, there are instruments that allow measuring emotional responses in terms of categories, such as Pick A Mood (PAM) \([28]\), or in terms of dimensional variables, such as the Self-Assessment Manikin (SAM) \([8]\). The former allows assessing emotional states as a discrete selection, while the latter consists of three-dimensional pictographic scales: arousal, valence, and dominance.

Several instruments that can be used to evoke emotions. For example, the International Affective Digitized Sounds (IADS) \([29]\), the International Affective Pictures System (IAPS) \([30]\), a battery of films for emotion elicitation \([31]\), and a public database of 360° videos \([13]\). Given that more immersive environments tend to elicit more intense emotional responses \([32]\), it is likely that emotion elicitation via HMD content is more effective than via traditional mediums.

To be able to gather ratings in a virtual environment, \([12]\) proposed to use an emotional grid to measure emotional
Table I: Used videos from database [13] in the experiment. To keep a constant duration for all stimuli, the selected time interval for each video is indicated. The quadrants or the orthogonal space with two dimensions: arousal and valence is stated (LALV=low arousal, low valence; LAHV=low arousal, high valence; HALV=high arousal, low valence; HAHV=high arousal, high valence).

| Video number | Name                                   | Short link                   | Time interval | Quadrant |
|--------------|----------------------------------------|------------------------------|---------------|----------|
| 1            | The Displaced                          | https://youtu.be/ecavbpCuvkI | 2 : 23 − 3 : 23 | LALV     |
| 2            | Solitary Confinement                  | https://youtu.be/nDwulYcboDU | 0 : 00 − 1 : 00 | LALV     |
| 3            | Malaekahana Sunrise                   | https://youtu.be/-bIrUYM-GjU | 1 : 20 − 2 : 20 | LAHV     |
| 4            | Great Ocean Road                      | https://youtu.be/asZtDBflbq0 | 0 : 00 − 1 : 00 | LAHV     |
| 5            | Jailbreak                              | https://youtu.be/vNLDRSDAljU | 2 : 39 − 3 : 39 | HALV     |
| 6            | War Knows No Nation                   | https://youtu.be/CiBooxLbNc | 4 : 44 − 5 : 44 | HAHV     |
| 7            | Walk the Tight Rope                   | https://youtu.be/JtAzMFcUQ90 | 0 : 27 − 1 : 27 | HAHV     |
| 8            | Puppies Host SourceFed For A Day      | https://youtu.be/c7sA3EdXUQ  | 0 : 04 − 1 : 04 | HAHV     |
the valence and arousal dimensions of the Self-Assessment Manikin (SAM) [2] (see Figure 1). The grid was stationary in the virtual environment. To get the final valence and arousal value for each participant, apparatus, video combination in the continuous rating system, we averaged all the ratings given by each participant in the given condition during the 60 second time window of the stimulus.

F. Procedure

The experiment began by giving the participant an introduction sheet regarding the experiment. The introduction sheet explained the general information of the experiment, important concepts (arousal, valence), the rating methods (continuous, retrospective), and the outline of the experiment. After having informed the participants about the experiment, they read and signed the informed consent as well as the demographics questionnaire. After that, participants tested the usage of the continuous evaluation plane by watching one video with a desktop before proceeding to the real experiment. In the experiment, as the order of conditions was randomized across participants, half of the participants saw the videos first in HMD and then on screen. The other half saw them first on-screen and then in HMD. Similarly, the order of the type of evaluation was randomized. Consequently, half of the participants did the continuous evaluation first, and the other half did the retrospective evaluation first. Participants were able to freely move, turn, and lock around during video playback. After finishing all of the four conditions, the participants filled the final questionnaire, which concluded the experiment.

Table II: Statistically significant effects of video (eight videos), presentation system (HMD vs. screen) and rating method (retrospect vs. continuous) on experiences emotion (valence and arousal scale) and perceived presence.

| Effect          | Parameter | dfN | dfD | F    | p    | η²  |
|-----------------|-----------|-----|-----|------|------|-----|
| Video           | SAM_A     | 7   | 13  | 23.76| <.001| 0.65|
| Video           | SAM_V     | 7   | 13  | 46.99| <.001| 0.78|
| Presentation system | Presence | 1   | 22  | 6.14 | .022 | 0.22|
| Rating method   | SAM_A     | 1   | 13  | 5.58 | .034 | 0.30|

G. Ethics

The experiment was approved by the local ethics committee of the Faculty IV of the Technische Universität Berlin (approval number FT-2019-05). The experimental procedure did not represent any risk for human health. The emotional effect produced by the videos did not have any long term effects.

IV. RESULTS

A repeated measures Analysis of Variance (ANOVA) was performed to analyze whether the presentation system (screen vs. HMD) and rating method (retrospect vs. continuous) had an effect on the evaluation of the videos. A summary of all significant effects that will be explained in the following sections is given in Table II.

A. Stimulus selection

As shown in Figure 2, there was a statistically significant influence of the independent variable video on the arousal and valence ratings (see Table II for test statistics). There are two videos in each of the four quadrants.

B. Influence of presentation system on presence

The presentation system had a significant influence on the sense of presence (see Table II for test statistics). As shown in Figure 3, the average value over all participants for the presentation system screen (M=2.85, SE=0.20) is lower compared to HMD (M=4.05, SE=0.16).

C. Influence of presentation system on valence

The presentation system had no significant influence on the valence. As Figure 4 suggests, the average value over all participants for the presentation condition is similar to HMD for both rating methods. The mean of retrospective and continuous rating in the screen condition were 5.03 (SE=0.16) and 5.09 (SE=0.14), respectively. In the HMD condition, the mean

Figure 2: Average values for SAM ratings for the dimensions arousal (y-axis) and valence (x-axis) over all participants.

Figure 3: Average values for presence ratings for the two presentation systems (screen vs. HMD) over all participants. Whiskers denote the 95% confidence interval.

Figure 4: Average values for presence ratings for the two presentation systems (screen vs. HMD) over all participants. Whiskers denote the 95% confidence interval.
The retrospective rating was 5.11 (SE=0.17) and 5.11 (SE=0.16), respectively.

Figure 4: Average values for valence ratings for the two presentation systems (screen vs. HMD) and the two rating methods (retrospect vs. continuous) over all participants. Whiskers denote the 95% confidence interval.

D. Influence of rating methods on arousal

Rating methods had a statistically significant influence on arousal (see Table [1] for test statistics). As shown in Figure 5, the average arousal value for the presentation system HMD over all participants for the rating methods retrospectively (M=5.30, SE=0.29) is similar to the continuous rating method (M=5.41, SE=0.27). For the presentation method screen, we have a lower arousal rating for the retrospective rating method (M=4.70, SE=0.30), compared to the continuous rating method (M=5.64, SE=0.29).

Figure 5: Average values for arousal ratings for the two presentation systems (screen vs. HMD) and the two rating methods (retrospect vs. continuous) over all participants. Whiskers denote the 95% confidence interval.

E. Intra-class correlations for arousal and valence

The agreement of the used rating methods (retrospect vs. continuous) regarding the ratings across participants was assessed by the inter-rater reliability (IRR) using a two-way mixed, absolute agreement, average-measures intra-class correlation (ICC) [33]. The average resulting ICCs regarding the eight videos suggest excellent reliability [34] for the valence score, total average ICC = 0.80, p < 0.05, and of good reliability [34] for the arousal score, total average ICC = 0.673, p < 0.05, indicating that (1) the rating methods had a high degree of agreement and (2) that valence and arousal were rated similarly across the rating methods.

V. DISCUSSION

A. Stimulus selection

From the results, we can see that the used stimuli were able to create the desired emotional responses in the participants. This can be seen in Figure 2, where the average emotional responses over each condition have been calculated for each video. Each quadrant from the origin (5,5) contains two videos as expected.

B. Influence of presentation system on presence

Regarding presence felt in the virtual world, we were able to repeat the results recorded from previous studies, e.g., [11], which indicates a greater feeling of presence in the HMD condition than in the screen condition.

C. Influence of presentation system on valence

When comparing the impact of the presentation system and the rating methods has on valence, no significant difference between the average value over ratings could be found. This could indicate that neither the immersiveness, which was implemented in our study by using HMD in contrast to a screen representation, nor the rating methods had a statistically significant effect on participants’ emotional reactions.

D. Influence of rating methods on arousal

On the other hand, when comparing the impact of the presentation system and the rating methods have on arousal, statically significant differences can be found. For the HMD condition, the two rating methods resulted in similar average values for arousal. For the presentations method screen, on the other hand, the continuous rating system resulted in statistically significant higher average values than the retrospective rating system. This effect could be addressed to the fact that participants were rating their emotional arousal in retrospect. Therefore, they might have underestimated the state in which they were during the stimulus presentation. It could also be that ratings are less accurate in the continuous rating condition because participants have to pay attention to the stimulus and to the rating tool at the same time.

E. Intra-class correlations for arousal and valence

The obtained intra-class correlations for arousal and valence indicate that both rating methods were rated similarly across the rating methods. We assume that also the continuous rating methods could prove as a valid measure in the assessment of emotional states. Based on the good to excellent intra-class correlations, we assume that different values for the two rating methods indicate the real state of participants and therefore were correctly obtained.
VI. CONCLUSION

It was shown that the selected 360° video stimuli could successfully be used to evoke the intended emotional reactions in the participants. Furthermore, evidence is provided suggesting that the feeling of presence was higher for the most immersive presentation system (HMD). The two different rating methods were able to capture the same construct (perceived emotion as measured on the dimensions arousal and valence) and therefore offer a real-time assessment of the emotional states of participants. A continuous rating task of emotional responses is useful for other experiments, especially for stimuli with a long duration, allowing a more natural rating procedure within the stimulus environment itself. Future research could help to study further the temporal effects of continuous ratings. For example, in traditional video, audio, or speech quality experiments. Another possibility could be to make only the rating method visible for the participants when they press a button. Then the scale could directly be in focus and quickly rated.

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