Assessing emotional responses induced in virtual reality using a consumer EEG headset: A preliminary report

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Abstract – We report on a pilot study involving emotion elicitation in virtual reality (VR) and assessment of emotional responses with a consumer-grade EEG device. The stimulation used HTC Vive VR system showing pictures from NAPS database within a specifically designed virtual environment. The stimulation consisted of two distinct sequences with 10 pictures of happiness and 10 pictures of fear. Each picture was contained in a separate virtual room that the participants traveled through along a preset path. The estimation employed EMOTIV EPOC+ 14-channel EEG headset and a custom-developed application. The software wirelessly received EEG signals from alpha, beta low, beta high, gamma and theta bands, time-stamped them and dynamically stored in a relational database for subsequent analysis. Our preliminary results show that statistically significant correlations between valence and arousal ratings of pictures and EEG bands are present but highly personalized. Simultaneous correct placement of VR and EEG headsets is demanding and precise localization of electrodes is difficult. In fact, if emotion estimation is not strictly necessary we recommend using devices with fewer electrodes. Nevertheless, we found the EEG to be effective. By acknowledging its limitations, and using the headset in the correct context, experiments involving emotions may be significantly amended.

I. INTRODUCTION

The aim of this paper is to evaluate the feasibility of detecting emotional reactions induced in virtual reality (VR) using a commercial EEG system. Previous studies have clearly demonstrated that elicitation of specific emotions with films, videos and pictures is challenging but possible [1][2][3]. High stimuli realism, sufficient personal relevance, and strong engagement have been suggested as the most significant factors contributing to immersion and presence leading to a successful elicitation [1][4][5][6]. Key advantages of exposure in VR overexposure *in vivo* are 1) greater flexibility, 2) safety, 3) cost-effectiveness [7].

VR and multimedia systems have been previously employed for detection, prevention, and treatment of phobias, anxiety and other stress-related mental disorders [5][7][8]. They have proven themselves very useful in a whole spectrum of therapies such as exposure therapy [9], stress inoculation therapy [10], stress resistance training [11], relaxation [12] and biofeedback [13]. Additionally, multimodal systems that combine VR and different multimedia formats have been successful as assistive tools in psychotherapy of PTSD patients [14][15]. However, only recent advancements in computer hardware have made it possible to render photorealistic graphics in real-time and with sufficient detail to provoke emotional responses on the same level as real-world photographs [16].

II. RELATED WORK

Recently, a number of related studies concerning detection of emotion-related phenomena using customer-grade EEG equipment have been published. One research proved initial usability of low-cost EEG equipment paired with VR in the detection of low-intensity and long duration emotion states such as moods [17][18]. This research obtained results that are in accordance with scientific literature regarding frontal EEG asymmetry, which supports the possibility of using the portable EEG as a reliable instrument to measure emotions in VR. In another research, the same type of low-cost EEG was demonstrated to be useful in providing emotional awareness information for synchronous collaborative editing systems [19]. These previous investigations motivated the exploration of emotional responses on EEG bands using low-cost commercial devices, as employed in our study. Also, scholars have been successful in combining commercial facial analysis software and EEG in emotion detection [20]. They have achieved 53% accuracy in emotion classification by fusing both information sources, which is higher than 19% accuracy when using only facial expression analysis tool.

III. COMMERCIAL-GRADE VR AND EEG SYSTEMS IN THE ASSESSMENT OF EMOTIONAL RESPONSES

HTC Vive is a high-end VR display device made by HTC and Valve Corporation (Figure 1) [21]. It is commercially available since April 2016. The device was designed to take advantage of available physical space and to use it as a free 3D environment within VR. This is accomplished by means of special sensors that allow a person to be tracked while moving through a predetermined space in the room. Tracking sensors are mounted on pedestals.

Movement involves moving users around the virtual world as they move in the room, but it also tracks movements and position of the headset so it is possible to move the camera inside the game and, for example, to descend into the VR environment or to approach and explore the objects in the simulation.

Fig. 1. HTC Vive headset (center) and controllers (left and right) [21].

In addition to the head mounted device (HMD) there are also two motion controllers that allow users to interact with objects within the VR environment. In VR, they are most often presented in the form of a hand or some facility that the user uses in the environment.

Recording of EEG signals was accomplished with EMOTIV EPOC+ 14-channel mobile system (Figure 2) [22]. This device is one of the few commercially available solutions that meet most of the required clinical electroencephalograph standards [23]. It was primarily developed for use in advanced Brain-Computer Interface (BCI) and for neurological research, but it can be applied in other areas such as research of emotion and attention. The system is highly mobile, easily operated and provides a powerful Software Development Kit (SDK) to programmers. Raw signals can also be recorded if needed.

Fig. 2. EMOTIV EPOC+ 14-channel EEG wireless headset [22].

Using the EMOTIV SDK we developed a Java desktop application (Figure 3) that can wirelessly record EEG signals from alpha, beta low, beta high, gamma and theta bands, time-stamped them and dynamically stored in a SQL database. The recording application was synchronized with the VR stimulation. Before measuring data, the user can define the rate of data collection per second, as well as minimums and maximums of recorded input data. This process is enabled due to the high possibility of interference with diode signals. Some of these issues can be reproduced by exerting a force on the diodes or facially expressing emotion.

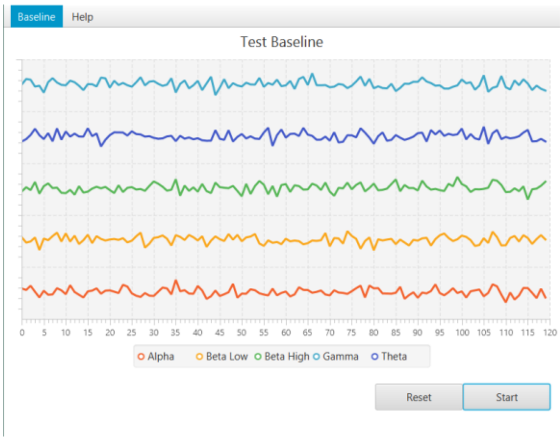

Fig. 3. Application interface for baseline acquisition and calibration of EEG measurements.

Before the recording starts, the user first performs a calibration or baseline measurement based on which data is measured together with stimulus presentation. The recording of baseline data lasts for 2 minutes, during which the user is asked to relax and have a neutral facial expression. After this process, it is possible to access the analysis window, where the evaluation of baseline measurement and test measurements is presented. The application also supports measuring participant's EEG signals while reproducing auditory stimuli in the form of music or various white noise signals.

IV. EXPERIMENTAL PROTOCOL

A homogeneous group of N=6 participants (5 men, 1 woman) with an average age 26.67 years (*std* = 1.11) participated in the experiment. Participants were visually stimulated with images from the Nencki Affective Picture System (NAPS) [24] embedded in a 3D VR environment. The NAPS affective multimedia database has 1356 realistic pictures and, together with its extensions NAPS BE [25] and NAPS ERO [26], is currently the largest such database with general semantic content. Pictures' context contains semantic categories, multi-word stimuli annotations and normative ratings in discrete and dimensional models of affect [27].

Each participant was exposed to two emotion elicitation sequences. A single sequence consisted of 10 VR rooms with 10 NAPS pictures, one picture in each room. The first sequence displayed pictures with dominating happiness and the second with dominating fear. The pictures were selected based on discrete emotion values from NAPS BE: 10 pictures had the highest level of happiness and the other 10 the highest values of fear. The length of each stimulus was exactly 15 seconds after which the participant enters an empty room without any emotion provoking picture to rest for 10 seconds. Therefore, in total each participant was exposed to 20 pictures in 20 VR rooms. Spatial and visual characteristics of all rooms, including those in rest phases, were identical (Figure 4). The rooms were initially designed to be emotionally neutral. Only emotion provoking content were the NAPS pictures (Figure 5).

Participants followed a preset path through the VR stimulation. They could freely change their direction of view but they could not change the path or speed of the movement in the 3D environment.

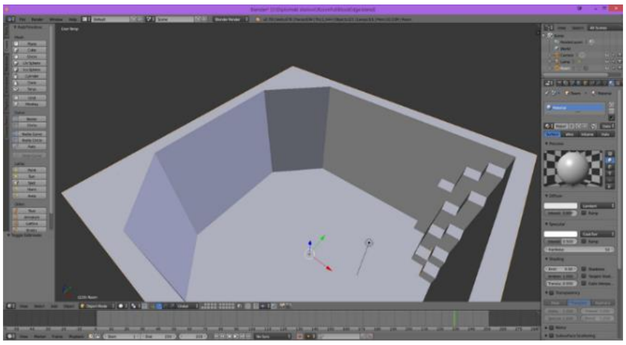

Fig. 4. A VR room during the development of stimulation sequences with Unreal Engine tools.

Fig. 5. A VR room with a picture from the NAPS database inserted on one of the walls.

Participants wore HTC Vive VR and EMOTIV EPOC+ headsets at the same time (Figure 6). This proved to be technically challenging because these systems were not designed for simultaneous use. Some HTC Vive elastic straps had to be loosened to provide space for EEG sensors. Also, before the experiment participants were advised to support by hand the front section of the VR headset because of its significant weight.

During the entire experiment, the illumination in the laboratory was dimmed as required by HTC Vive manual and psychophysiological laboratory guidelines [28]. Participants removed the headgear and rested between the two sequences. The exposure resumed only after the participants were fully relaxed.

Fig. 6. On the left, a participant is wearing VR and EEG headsets during the experiment. One of the HTC Vive VR sensors is visible in the background. The supervisor station is on the right.

V. RESULTS

In the experiment, we monitored alpha (α), beta low (β_L), beta high (β_H), gamma (δ) and theta (θ) bands. The signals were recorded at 128 Hz sampling rate. EMOTIV EPOC+ acquisition software automatically filtered out the noise and removed artifacts if electrodes were appropriately positioned on a participant's scalp. Features were derived off-line from the signals' values stored in the SQL database. In this preliminary analysis we cal,culated one feature: absolute difference between signal average (AVG) and baseline for each stimulus (BAS).

$$\begin{aligned} AVGBAS_{\alpha} &= |\alpha_{AVG} - \alpha_{BAS}| \\ AVGBAS_{\beta_L} &= |\beta_{L_{AVG}} - \beta_{L_{BAS}}| \\ AVGBAS_{\beta_H} &= |\beta_{H_{AVG}} - \beta_{H_{BAS}}| \\ AVGBAS_{\delta} &= |\delta_{AVG} - \delta_{BAS}| \\ AVGBAS_{\theta} &= |\theta_{AVG} - \theta_{BAS}| \end{aligned} \tag{1}$$

The feature $AVGBAS$ was obtained in 10 sec fixed windows for each stimulus in both sequences. The feature was then correlated (Pearson correlation coefficient r) with valence (Val) and arousal (Ar) emotion values from the NAPS database for the displayed picture. Correlation measures between aggregated average $AVGBAS$ for all participants and picture emotion values are shown in Table 1. Valence and arousal of pictures in the happiness sequence are denoted Val_H and Ar_H, while valence and arousal in the fear sequence are Val_F and Ar_F, respectively.

TABLE I
Correlation measures (r) among aggregated average $AVGBAS$ feature for all participants and picture emotion values per each EEG band.

	α	β_L	β_H	δ	θ
Val_H	-0,112	0,009	0,113	0,054	-0,063
Ar_H	0,019	0,003	0,182	-0,017	0,081
Val_F	0,168	0,071	0,123	0,063	-0,259
Ar_F	0,019	-0,054	-0,012	0,051	0,047

As can be seen in the table the largest correlation pairs in the happiness sequence are (β_H, Ar_H) and (β_H, Val_H). The fear sequence stimulated statistically more significant correlations (θ, Val_F) and (α, Val_F). This is in agreement with findings from previous studies where stimulation of negative polarity emotions is more powerful than with positive emotions. Alpha and theta bands indicate that participants were simultaneously less relaxed and experienced stronger cognitive processing than with stimuli in the positive sequence, as should be expected. Although this study is only preliminary, it acquired quality data for further analyses.

VI. Discussion and Conclusion

The experiment demonstrated that VR is a great asset for emotion elicitation techniques surpassing the potential of pictures, films, and video clips. Contemporary VR systems enable development of provoking storylines with personally meaningful narratives. This is of the utmost importance for a successful emotion stimulation. The other vital factors are realistic and engaging visuals. Continuous progress in computer graphics has made it possible to eliminate differences between photographs and computergenerated graphics. We found that using modern development tools creation of VR environments is swift and intuitive. Subsequent customizations are also greatly simplified. During the design, it is very important that a VR room is emotionally unprovocative and that participants are actually looking at a stimulus in the room. This can be accomplished by forcefully directing their line of sight when entering a room. Constant monitoring of participants' point of view from the supervisor's station should be obligatory.

Unfortunately, consumer-grade EEGs have not yet reached capabilities of professional laboratory devices. Nevertheless, we found EMOTIV EPOC+ EEG ideally suited for student experiments and quite adequate in the detection of emotion-related phenomena where exact placement of electrodes is not crucial. The system is very easy to work with, develop new code and record signals. However, the headset is not ideally suited for usage in tandem with a VR device. At the current level of development, these two technologies (EEG and VR) have conflicting requirements in experimental protocols. Better immersion requires obscuring upper face region and forehead with a large display, and elastic straps needed for immobilizing the heavy screen cover wide scalp regions. Calibration of EEG's electrodes' location is particularly demanding. Electrodes must be placed within c. 5−10 mm of the ideal spot to record signals with an acceptable artifact level (i.e. noise). This is especially noticeable for prefrontal (dorsolateral and ventrolateral) electrodes because the VR display almost completely obscures these brain regions and cannot be moved. However, VR headset straps can be loosened and even partially removed to allow access to parietal and occipital brain lobes. However, this may limit participants' head movements or even cause some physical discomfort and must be taken into account during the planning of an experiment.

EEG spectral bands are a good measure of attention and alertness. To obtain power spectral analysis of EEG activity, a simpler single-electrode headset can be used. Such device is more easily manageable and could be compatible with a VR headset simplifying the whole problem with the simultaneous use of EEG and VR devices.

Our experience in this study shows that a number of questions must be considered to accomplish an emotion experiment with consumer-grade equipment. But if the protocol is carefully designed all issues can be successfully solved. Accurate electrode localization remains an open challenge, however.

VII. Acknowledgement

We would like to kindly thank the company "Little Green Men Games" (Intercorona d.o.o.) and their employees for the contribution of the HTC Vive equipment and participation in the experiment.

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