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Physiological data collection to detect emotional state during XR experiences: a pilot study in military education

Serena Ricci*
DIBRIS, University of Genoa, Italy; NTNU, Norway

Simone Grassini†
Department of Psychosocial Science, University of Bergen, Norway

Francesca Ghigliazza ‡
DIBRIS, University of Genoa, Italy

Ludovica Viola §
DIBRIS, University of Genoa, Italy

Stian Kjeksrud ¶
Norwegian Defence University College, Norway

Ekaterina Prasolova-Førland ‖
Norwegian University of Science and Technology, Norway

Figure 1: XR Experience. Left: Combined 360º video/embodiment session where participants are embodied as a civilian. Center: Virtual perpetrator the user must talk to during the dialog part of the experiment. Right: Collaborative map exercise with multiple participants simultaneously.

ABSTRACT

Virtual and Extended Reality (VR/XR) is used to facilitate education in many disciplines, given its possibility to deliver engaging and immersive contents that can induce empathetic reactions, thus optimize learning. Usually, the emotional changes related to XR experiences are assessed through qualitative tools, such as questionnaires, that however do not provide real time objective measures. Physiological indexes such as Skin Conductance and Heart Rate offer an alternative, being associated with stress response, emotional arousals, and empathy. The goal of this pilot study was to assess whether Electrodermal Activity and Photoplethysmography can detect emotional state and empathy changes in the specific context of teaching civilians protection in the military setting. We collected physiological data of 15 subjects undergoing a lecture introducing the topic, followed by a VR-embodiment/360º video session where they embodied a civilian victim and the perpetrator of violence, an interactive dialog with a perpetrator and a collaborative VR-map session. Preliminary results show differences in both the tonic and phasic electrodermal activity across different conditions, suggesting that physiological indexes can help understanding the emotions associated with immersive training activities.

Index Terms: VR—XR—Emotional State—Empathy— Military Education—Physiological Data—Electrodermal Activity (EDA)—Photoplethysmography (PPG)

1 INTRODUCTION

Extended reality (XR) and Virtual Reality (VR) allows to create 3D spaces that react to human behavior, enabling real-time communication between humans and the virtual environment [24]. As a result, XR has a wide range of applications, including the educational sector, especially in risky situations [19, 36]. This is probably due to the fact that the “sense of presence” [13] promoted by these technologies may positively mediate learning [20].

One of the earliest uses of Virtual Reality (VR) has been in military training [26, 38]. The uses of VR in the military sector traditionally focus on preparation to military operations in the battlefield; however, another interesting field, not extensively explored, is the use of VR simulations to educate military personnel for the protection of civilians in armed conflict, which requires soft skills and competencies that move far beyond learning mere motoric skills [16]. Hence, stimulating the understanding of social situations through VR applications is still under-developed, but it has recently found support in the scientific literature [16, 40], as it can induce empathetic reactions that might not be provoked by traditional teaching methods. In fact, VR simulations have shown to efficiently improve empathy (i.e., psychological phenomenon referring to the ability of an individual to understand and share the feelings of others [14]) in several different contexts [6, 21, 37]. Empathy plays a crucial role in social interactions and leads to prosocial behavior, social competence, and better adjustment [8].

One of the main aspects of assessing whether a VR experience evokes empathy or, more generally emotional changes, is how to measure and assess such changes. Traditionally, they are evaluated using qualitative self-assessment tools, as well as interviews, surveys and questionnaires [15]. However, information is usually collected at the end of the experience, thus not capturing real time or quick variations the individual may not be aware of. Also, social desirability bias can affect the results, as participants might feel uncomfortable in reporting their true emotions [10]. A possible alternative, which has been explored in the last decades, is the monitoring of physiological changes, particularly brain activity, electromyography, motion analysis, skin conductance, measures related to blood flow changes,

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*e-mail: serena.ricci@unige.it
†e-mail: simone.grassini@uib.no
‡e-mail: ghigliazzafrancesca@gmail.com
§e-mail: ludovica.viola@edu.unige.it
¶e-mail: skjeksrud@mil.no
‖e-mail: ekaterip@ntnu.no

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eye movements and facial expressions [15]. Indeed, collecting biological data provides real time quantitative measures, that can better determine whether a specific experience leads to emotional changes.

Among the possible alternatives, we have selected Electrodermal Activity (EDA) and Photoplethysmography (PPG), as the acquisition systems are small and comfortable for the user to wear. This is important, as cumbersome and uncomfortable systems could induce negative feelings that might bias the results [25]. EDA and PPG are not consciously controllable; therefore, their variations have been associated with stress responses, arousals, empathy, human behavior, cognitive, and emotional states [9, 26, 31].

The goal of this preliminary study was to assess whether EDA and PPG measures can provide information about the emotional state and empathy level in the specific context of threat-based approach to protection of civilians education at the Norwegian Defence University College [23]. The project seeks to improve engagement in and knowledge about the subject with the help of XR. More specifically, students should be able to:

- Explain the role, utility, and limitations of military force in protecting civilians;
- Analyze variations in threats to civilians in armed conflict;
- Evaluate how military forces can reduce violence against civilians.

The EDA and PPG measures have been used in previous research, for example, to study human responses to stressors while experiencing an immersive environment [28], and anxiety [33]. However, studies combining EDA, PPG with XR in military training are limited to vitals monitoring to measure resilience under high-stress conditions [7].

We collected real time physiological data while students were exposed to drama-rich embodiment sessions and 360 º videos, a dialog with an avatar, and a collaborative VR-map session, with the ultimate goal to gather more information about user engagement, through quantitative measures.

This study is part of a broader project aimed at investigating new instruments and methods to teach master's degree students and military staff officers the importance of civilian protection in armed conflicts, a topic whose significance is usually poorly understood by countries and organizations [16, 18].

2 METHODS

For this pilot study, we enrolled 15 participants (mean ± STD age: 39 ± 4 years, range 34-47 years, 2 women), who attended the master's degree program at the Norwegian Defence University College and have a military experience of 20 ± 3 years. All the participants but 2 have little to no prior VR experience. Subjects were divided in four 3-5 people groups who who engaged in the XR experience at the same time (Fig. 2). The study was approved by the Norwegian Centre for Research Data and subjects signed a consent form prior to the start of the experiment.

2.1 Experimental Design

The XR experience was delivered using a HP Reverb G2 headset (HP, USA) and included three parts (Fig. 3; see also [16, 18] for further information on the experiment design): (i) embodiment/360º videos; (ii) active dialog with perpetrator; (iii) collaborative exercise occurring in a virtual map.

These sessions are preceded by a baseline period of 30 minutes, introducing the topic (i.e., threat-based approach to protection of civilians). Before the experiment, after each phase, and at the end of the session, subjects filled out questionnaire about self efficacy [3], motivation, empathy [34], perceived learning [27], cognitive and technical aspects of the experiment, as well as behavioral changes and reflective thinking, general satisfaction, value [2] and usability [4, 16].

2.1.1 Embodiment/360º video

This part lasted around 30 minutes (including setup) and started with a session in front of a mirror in a virtual environment. Users embodied a civilian victim, and their physical movements were mirrored by their avatar. Then, they were immersed into a 8-minute 360º video (produced using a Z CAM v1 PRO), combined with embodiment, still being able to see the virtual replica of the body and hands while seated in an apartment and looking down, as well as keeping eye contact with the characters [16, 17]. In the video, participants embodied a member of a family attending a birthday celebration interrupted by violence events and could listen to conversations and broadcasts related to the conflict (Fig. 1). After embodying the civilian victim, students embodied a perpetrator of violence, namely a member of an armed group [16]. Similar to the first video, the embodiment started in front of a mirror, and was followed by a scene taking place in the facility of the armed group during a meeting with a militia leader. Here, perpetrators planned and discussed ethnic cleansing of a particular area, where the family members of the first video belong to.

The aim of the videos was to trigger affective and cognitive empathy linked to victims and perpetrators of violence. The empathy linked to the victims is straightforward, as most students likely understand and feel the gravity of the situation. Conversely, cognitive empathy linked to the perpetrators is not intended to push towards sympathetic feelings, but rather to produce an understanding of the perpetrators' motivations that is an essential part of threat-based approach to protection of civilians [16, 23].

2.1.2 Dialog

Users interacted with a script-based virtual perpetrator, in a realistic war-torn urban virtual environment. Within the scene, there were military equipment, as well as militia soldiers (Fig. 1). Both the scene and the virtual perpetrator have been implemented using the multiplayer platform CORE (Fynd Reality, Norway [1]). In this phase, each participant played the role of an intelligence officer standing in front of the virtual perpetrator and trying to collect information about the ongoing conflict and the armed group [16].

Figure 2: Example of an experimental session. Subjects are equipped with both the VR headset and EDA and PPG sensors.

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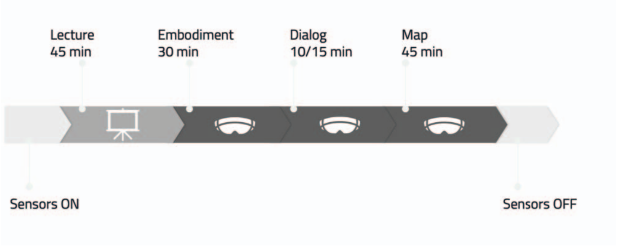

Figure 3: Experimental Design

The avatar guided a series of possible conversations, and students, by using the controllers of the VR headset, could choose different questions and answers, presented in the form of dialog boxes and text. The questions covered security concerns, surrounding situations and civilians' treatments [16]. According to the question/answer provided, the virtual character reacts differently; he can be friendly and hospitable, as well as angry and hostile (Fig. 1). This part lasted 10 to 15 minutes, depending on the user.

2.1.3 Collaborative Map Exercise

This part consisted of a collaborative multiplayer task, developed using the CORE platform, where students were immersed in a 3D virtual map of a fictitious country affected by conflicts (Fig. 1). By navigating the map, they could find clues that would help them collect information to understand the situation and analyze threats to civilians. The map included 18 cues (e.g., social media-posts, broadcasts, videos, newspaper articles). To collaborate and interact to each other, students could see their peers as schematic avatars and could communicate verbally, being in the same room. During the simulation, which lasted around 45 minutes, and had the goal of enhancing analytical skills, the students were free to decide how they collaborated [16].

2.2 Data Collection

During the whole session, EDA and PPG data have been collected using a Biopac MP150 system (Biopac System Inc., Cam USA) and AcqKnowledge 5.0.6 with sampling frequency of 2000 Hz. For all the measurements, we used a wireless BioNomadix amplifier; we positioned two pre-gelled Ag/AgCl foam electrodes (Biopac, EL507) on the middle and index fingers of the non-dominant hand to collect EDA, and a Pulse Transduced (BN-PULSE-XDCR) on the subject's ring finger. The correct positioning of the sensors was checked after each stage of the experiment, and electrodes were replaced halfway through the experimental session. Due to technical issues, EDA data of three subjects and PPG signals of four participants could not be used for the subsequent analysis.

2.3 Data Analysis

For each subject, the signal was divided into baseline (i.e., lecture), embodiment and dialog, thus excluding the final part concerning the collaborative map task, as this exercise was characterized by movements which could impact the quality of the signal. Furthermore, our goal was to assess whether and how EDA and heart rate were affected by the XR experience, particularly when the subject embodied another character other than himself. All the data have been analyzed using MATLAB 2021b and down sampled at 1000Hz. As normality condition was not satisfied (Kolmogorov-Smirnov tested), we used Wilcoxon signed rank test to assess EDA, PPG variations across different phases of the experiment.

2.3.1 Electrodermal Activity

EDA Data have been preprocessed and analyzed using the MATLAB plugin Ledalab [5]. After applying a low-pass filter (first-order Butterworth filter, cut-off frequency 35 Hz), data have been smoothed (type: gaussian window, width 8 samples). Then, the signals have been visually inspected to remove artifacts, namely periods during which there was a physical disconnection of the electrode or movement-related artifacts. Before computing the Continuous Decomposition Analysis [5], data have been further down sampled to 2Hz. We have then analyzed: (i) tonic activity; (ii) average phasic activity; (iii) number of Skin Conductance Responses (SCR) above the threshold (0.01 mS) normalized by the length of the recording.

2.3.2 Photoplethysmography

Data were firstly filtered through a Finite Impulse Response (FIR) band-pass filter (order n=22; window Wn=fc/(Fs/2) Fs: sampling frequency 1000 Hz, fc: cut-off frequency 2Hz; [29]). Then, motion artifacts have been removed using the following approach: peaks whose values were above or below 2 standard deviations from the mean have been identified as artifactual peaks. For each peak, we replaced the 500 points before and 500 points after it with the average of the signal. Then, visual inspection of the data was performed to further detect noisy parts of the signal. To compute the heart rate, we have used the open-source "PPG Beat Detection artifact" [11]; this algorithm allows to detect heartbeats in PPG signals and then calculate the heart rate.

3 RESULTS

To assess whether different stages of the experiment showed variations in the physiological parameters, we computed the average EDA tonic activity and phasic activity, number of significant SCRs normalized by the length of the recording, and heart rate. Visual inspection of the data revealed that the EDA tonic activity was lower during the dialog, with respect to the other phases of the experiment (Fig. 4). Statistical testing revealed a significant difference between (i) baseline (mean ± S.E. 8.01 ± 1.24 mS) and dialog (4.56 ± 0.50 mS; p=0.010); (ii) embodiment (6.98 ± 1.13 mS) versus dialog (p=0.040; Fig. 4). The phasic activity of the baseline (0.14 ± 0.02 mS) was significantly higher than the other phases (embodiment: 0.07 ± 0.01 mS p=0.009; dialog: 0.07 ± 0.02 mS p=0.017). Conversely, the number of significant SCRs normalized by the length of the recording, and heart rate did not significantly change across the three phases of the experiment, even though they slightly increased in the dialog session (Table I).

4 DISCUSSION

As stated above, participants were asked to fill out multiple questionnaires, before and after each experimental session. Preliminary results revealed that the XR experience contributed to a better understanding of the main principles of the threat-based approach. The students acknowledged the value of the XR experience for adopting alternative perspectives and its importance as an integrated component of an educational curriculum. Students' emotional responses

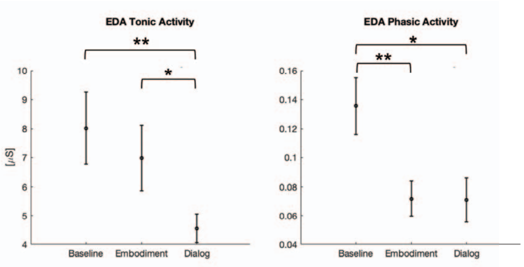

Figure 4: Left: Average EDA Tonic Activity in the three phases of the experiment. Right: Phasic activity *$p<0.05$ **$p<0.01$;

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Table 1: Normalized number of SCR and heart rate in different phases of the experiment

	Baseline mean (S.E.)	Embodiment/360º mean (S.E.)	Dialog mean (S.E.)
Normalized nSCR [n/minute]	22.0 (1.2)	22.6 (1.2)	2.0 (2.0)
Hearth Rate [bpm]	63.5 (1.6)	62.9 (1.9)	66.1 (2.2)

to the 360º videos in which they were embodied as civilians and perpetrators appeared to be impacted by the intervention. There were however differing opinions on the role of embodiment for a number of reasons. One of the possible causes might be that the students were not fully acclimated to their virtual bodies prior to and during the video's narrative. After the embodiment/360º video experience, subjects seemed to have understood the learning goal of the application, and positively rated the embodiment experience. Similarly, questionnaires on perceived learning and cognitive aspects both after the dialog and after the collaborative exercise received mostly positive ratings [16, 18]. Altogether, preliminary findings from the questionnaires suggest that the XR application can be a valuable educational instrument to help students reflect on the topic of protecting civilians during armed conflicts.

Regarding the EDA activity, differences between the baseline and the experimental condition led to many considerations. Firstly, a lower tonic activity during the dialog phase, with respect to the other parts of the experiment, might be explained by the fact that participants were excited to be part of the experiment, and to have the possibility of using VR, as many of them had little to no experience with this technology. Then, as soon as the experiment proceeded, their emotional arousal gradually decreased. In fact, studies comparing the emotional arousal of gamers versus non-gamers report lower values for the first group [30]. Another explanation could be that the dialog session was quite repetitive in terms of interactions; the user used the controllers to select a question and waited for the avatar to respond before asking the following one. Conversely, during the embodiment, participants did not know what to expect and therefore are more excited and engaged. This result is further supported by post-experiment feedback and questionnaire responses, as many participants reported that the embodiment/360º was more engaging than the dialogue and map parts of the experience. This could be attributed to the sense of social presence and interaction with the characters (e.g. characters making eye contact with the user).

Another interesting result is the high phasic activity at baseline, which is significantly different than embodiment and dialog experiment phases. This suggests that participants were more stressed at the beginning of the experiment, and less during the XR experimental conditions [35]. On one hand, this result can be seen as straightforward: people do not know what to expect before the experiment, and therefore are stressed. Then, as soon as they feel at ease, and are more familiar with the environment, their stress level decreases. However, a fascinating conjecture, supported by recent research studies, can be that the VR experience is responsible for reducing stress [12, 22]. Most likely, the results are a combination of better knowledge of the task to perform, and use of an engaging technology.

The protection of civilians from perpetrators is a new task, that is still not well understood by military forces. It includes a better comprehension of the perpetrators of violence, to facilitate tailored responses. Existing knowledge on learning in XR suggest that one way of learning is by imitating others [32, 39].. The 360 video-scenarios offer an opportunity to investigate cognitive empathy, affective empathy, and somatic-embodiment that has documented effect in terms of induced empathy, attitude and behavior change [32, 39].

5 CONCLUSION

The goal of this pilot study was to investigate whether non-invasive physiological measures, such as Electrodermal activity and Photoplethysmography measures can provide quantitative information about the emotional state and empathy level in the specific context of teaching threat-based approach to protection of civilians to military officers. To do so, we collected EDA and PPG data of subjects who performed an XR-based education activity. Preliminary results show that EDA can discriminate between different phases of the experiment. Certainly, additional analysis should be performed to relate these measures to subjective questionnaire delivered during the experiment, as well as to further investigate PPG variations. Nevertheless, this study supports the idea that physiological measures can help understanding the emotions underlying XR education activities, especially in those cases where a social desirability bias is strong. Moreover, having a real time feedback on the emotional state of the user, can support the creation of more engaging and personalized experiences that ultimately optimize learning. At the moment, we are exploring the possibilities of creating a ChatGPT-based virtual perpetrator that will dynamically react to the user based on several parameters, including the user's emotional state.

The video of the project can be found here: `https://www.youtube.com/watch?v=DKulNaGoEBc`

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