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Psychophysiological Approach for Measuring Social Presence in A Team-Based Activity: A Comparison Between Real and Virtual Environments

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***Abstract*—Teamwork is becoming increasingly important in today's engineering and product design professions. In an effort to enhance teamwork and collaboration, our approach relies on adopting a psychophysiological approach for determining how participants' feelings of social presence in a virtual reality environment in comparison to the "real" world. Using a combination of ECG data and participant feedback from an anonymous questionnaire, our comparative analysis shows that participants feel more relaxed and have a greater sense of participation in the virtual environment. That could provide a stronger theoretical basis for the development of virtual collaborative projects in the future.**

***Index Terms*—social presence, virtual reality, psychophysiology, ECG**

I. Introduction

Engineering projects in the real world need interdisciplinary teams that work on loosely defined problems [1], [2]. Rarely do engineers work individually, and teamwork is, therefore, crucial [3]. In fact, teamwork is one of the graduates' attributes most appreciated by higher educational institutes due to its importance in the engineering profession [4]. Therefore, engineering accreditation bodies consistently require university programmes to demonstrate the development of student teamwork skills, regardless of whether graduates decide to pursue a career in industry or academia [5]. This is especially true since teamwork requires students to collaborate and share information with each other, which ultimately leads to improved student learning and achievement [6], [7].

According to the literature, virtual reality (VR) creates opportunities for producing engaging collaborative experiences that are often measured by "feelings" of social presence. Here, social presence is often characterised via a network of interpersonal relationships and communication methods [8]. It has special significance for establishing and maintaining online behaviour and social interaction [9].

Consequently, the aim of this paper is to investigate claims of social presence in a virtual collaborative environment. In this case, we determine whether teamwork and collaboration can be achieved in a virtual environment and use sensors to verify these feelings of social presence. In fact, physiological information collected using these sensors can help us in understanding student mental load, mood swings, and psychosocial reactions [10]. As explained by Biocca and colleagues [11], it is possible to measure social presence via physiological linkage. Additionally, electromyography (EMG), electroencephalography (EEG), electrodermal activity (EDA), and electrocardiogram (ECG) activity are typical psychophysiological measures appropriate for physiological linkage experiments. For the purpose of our investigations, we decided to focus on collecting ECG information since it is one of the most commonly used methods for determining psychological stress states [12].

Moreover, we compare the effectiveness of teamwork and collaboration in the "real" world with that of the "virtual" environment. Based on participant results, we predict that students' ECG data will change slightly from the virtual to the real world.

The remainder of this paper is structured as follows. The methodology of design and conduction of the experiment has been presented in section 2. The next section provides the key data findings from the questionnaire and ECG sensors through graphics. Finally, the conclusion and future suggestions are presented in Section 4.

II. Methodology

As previously mentioned, the aim of this research is to investigate "feelings" of social presence in an immersive "metaverse" environment. How do students "feel" when working on a collaborative game-based task in comparison to the real, physical world? To answer this question, a simple VR game (SeperateWoodenBlocks) was developed. Moreover, participants' feelings of social presence in the physical world were compared. To obtain more accurate data, this project provides multi-modal data, which has been obtained by a physiological method such as heart rate from sensors and participant responses from a questionnaire.

The ECG sensor was used to determine changes in stress. Raw data was recorded by placing electrodes on participants' bodies. In this experiment, the right arm (RA) and left leg electrodes (LL) were used to record changes in cardiac current, as shown in Fig. 1. The effectiveness of measuring Heart Rate Variability (HRV) has generally received more attention as the best stress indicator [13]. HRV data often shows variations in the space between RR intervals, or repeated heartbeats in time [14]. The features of HRV can be obtained by analyzing ECG raw signals in the time domain. Regarding the short data acquisition time (less than 15 minutes), only SDNN (the standard deviation of RR intervals, where R is the peak of a heartbeat), RMSSD (the root mean square of successive differences of RR intervals), and pNN50 (the corresponding percentage of NN50, where NN50 means the number of interval differences of successive RR intervals greater than 50 ms) were used as the sign features of HRV. The formulae for the features are shown in table I [15].

Current psychophysiological evidence from the literature suggests that HRV data can be influenced by external factors, which may include psychological stress [16]. Generally, lower HRV often translates to higher stress. HRV data does not have an optimal standard range, since it is affected by many factors such as age and lifestyle [17]. Therefore, since it is 'personalised' data, we will show ECG data for each individual and how this varies according to our different stimuli.

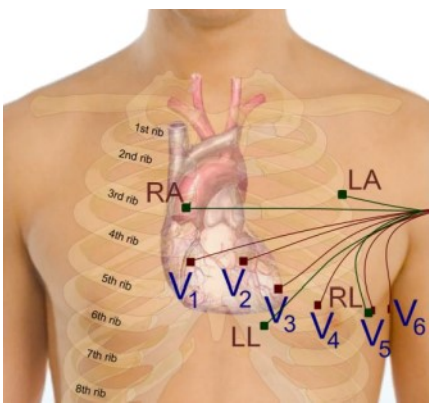
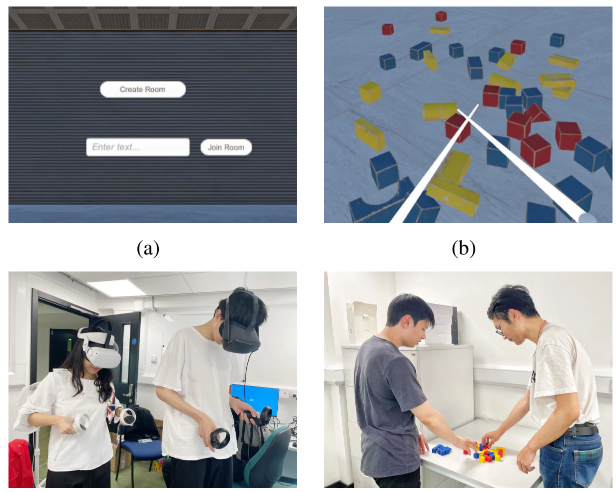


Fig. 1. Electrode positions of the ECG sensors used to measure social presence.

TABLE I
ECG FEATURES AND THEIR CORRESPONDING FORMULAS

No.	Symbol	Unit	Equation
1	SDNN	ms	$\text{SDNN} = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (\text{RR}_i - \overline{\text{RR}_i})^2}$
2	pNN50	%	$\text{pNN50} = \frac{\text{NN50}}{\text{Total NN}} \times 100\%$
3	RMSSD	ms	$\text{RMSSD} = \sqrt{\frac{1}{N} \sum_{i=1}^{N-1} (\text{RR}_{i+1} - \text{RR}_i)^2}$

SeprateWoodenBlocks was chosen as a suitable VR game for multi-person collaboration and was developed using Unity3D. The objective of the game was to separate a set of disordered wooden blocks. Teammates needed to communicate with one another to discuss how to separate the blocks, by either colour or shape. As shown in figure 2(a), users entering the VR game must first choose to either to create or join a room. The first user to enter the VR game can click the 'Create Room' button to enter the game so that the interface shown in figure 2(b) appears. Subsequently, all the wooden blocks can be grabbed, thrown and placed via interaction with the controller. Participants can enter the same room by entering the appropriate IP address. All users need to be using the same LAN (Local Area Network), so they can communicate with each other. When two teammates are ready, they can start a cooperative game as shown in figure 2(c). After completing the VR game, participants subsequently need to play the same game in reality and grab wooden blocks that were placed on a table, as shown in figure 2(d).



(a) (b) (c) (d)

Fig. 2. The process of playing the games in both VR and real environments. (a)the first screen displayed in the headset after running the VR game. (b) players enter the room of the VR game with disordered wooden blocks on the floor (c) a group of participants is separating wooden blocks in a VR game (d) a group of participants is separating wooden blocks in reality

The experiment was designed to measure participants' cardiac electrical signals using ECG sensors from the Shimmer kit in three phases: the resting state, the cooperative state in the VR game, and the physical world. That means there were three steps: the first step is to keep subjects in the resting state for 2 minutes and not allow them to move or talk; then two of them as a group playing the VR game Separate Wooden Blocks is the second step, which may take them 3 minutes. Between the second and the last steps, there were 3 minutes for volunteers to take a rest. In the third step, participants needed to play the same cooperative game in reality for around 2 minutes. During those three steps, participants' physiological data was collected using our ECG sensors. The 10 participants selected by convenient sampling are students from the University of Glasgow. A short introduction was provided for volunteers before the start of the experiment. Students were told that their participation would not influence their marks and that any information they gave would be kept anonymous and private. The first five questions of our online questionnaire invited participants to provide feedback on their feelings about completing virtual reality tasks, including satisfaction, engagement, and excitement (on a scale of 1 to 5, with 5 being the highest). Questions 6 to 8 asked participants to answer their attitudes towards the role of virtual reality in cooperative tasks. The ninth question asked the participants whether they would like to use the VR system again for teamwork.

III. Results and discussion

Data from one of the participants were discarded since there was an unexpected problem with the headset. Therefore, data from 9 subjects were analysed in this study. The calculated results of HRV features are summarized in figure 3, which were used to measure the stress levels of our participants.

According to our results, the SDNN data of 89% of the participants dropped with the state changing from resting to VR and then to reality. The RMSSD data of 67% of the participants and the pNN50 data of 44% of the participants dropped with the state changing. Only the data from sample 2 showed an increase in all features when making a comparison between the data in reality and that in the VR environment.

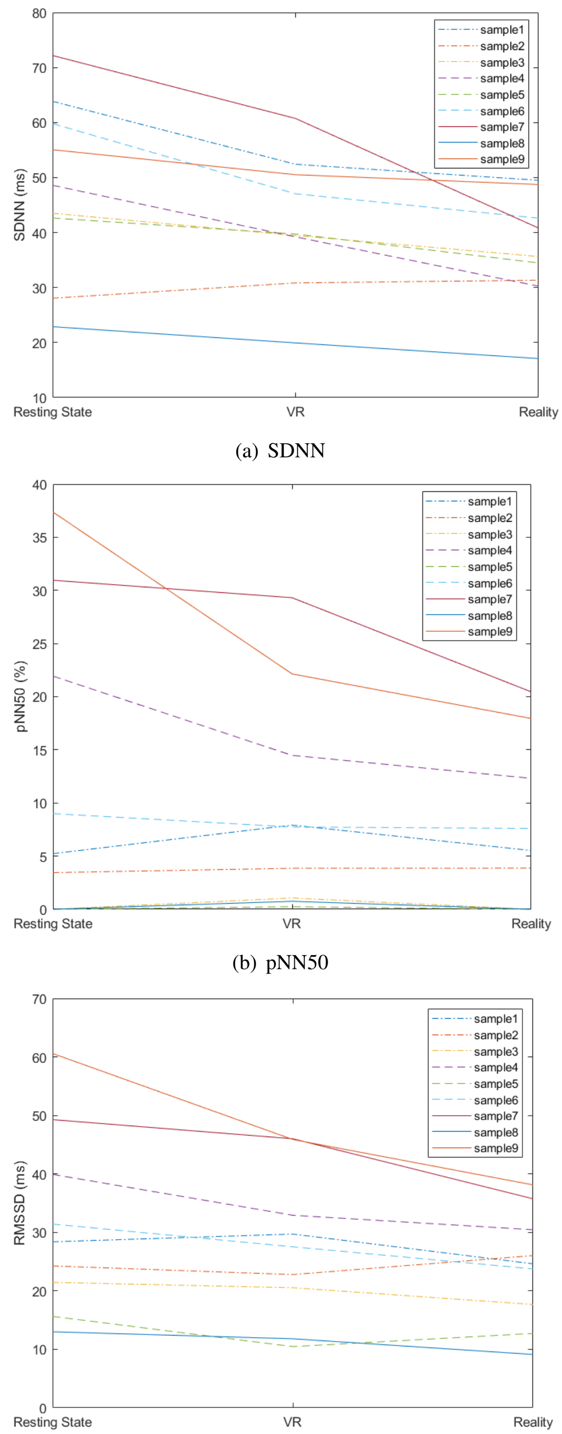
The mean of standard deviations for SDNN (6.394) was larger than that for RMSSD (4.226) and pNN50 (2.731), showing that it would be easier for researchers to figure out those emotional changes by using the SDNN as the feature of HRV. Also, the standard deviation of pNN50 for sample 2 (0.238), 3 (0.611), 5 (0.139), 6 (0.769) and 8 (0.434) were all less than 1. Considering the possible errors of the sensor itself, it was not suitable to use pNN50 as the characteristic parameter of HRV in this sample environment.

TABLE II
AVERAGE FEATURE DATA OF HRV FOR EACH STATE

	SDNN		pNN50		RMSSD	
	Mean	SD	Mean	SD	Mean	SD
Resting	48.509	16.202	11.993	14.411	31.549	15.770
VR	42.210	12.182	9.722	10.293	27.518	12.852
Reality	36.718	10.131	7.525	7.795	24.250	9.818
Resting-VR	6.299	5.215	2.271	5.639	4.031	4.711
VR-reality	5.492	5.995	2.197	2.844	3.268	4.284

Table II summarizes the mean and standard deviation (SD) of the signal features of HRV, which could be used to show the trends with the state changes. All the values of SDNN, pNN50, and RMSSD as HRV features in time domain, were dropped when changing from resting state to VR state and then to reality state. It could be deduced that participants tended to experience more stress in reality than in VR environments. However, as the standard deviations of the features were all extremely large, the mean value of drops could not be used as the standard to determine how much stress would be gained with changes in the environmental state. It also showed the phenomenon that each participant was affected differently by the state of the environment.

Table III, which lists the questionnaire's results, the mean score of the sense of engagement was the highest and the



(a) SDNN

(b) pNN50

(c) RMSSD

Fig. 3. Changes in HRV features of each participant.

TABLE III
PERCEPTION OF COLLABORATION IN THE VR ENVIRONMENT.

	Mean	SD
Satisfied	4.44	0.73
Engaged	4.67	0.50
Excited	3.67	0.71

SD was also the smallest (0.5), which statistically suggested that the participants generally felt a sense of engagement, with data concentrated on agree and strongly agree.

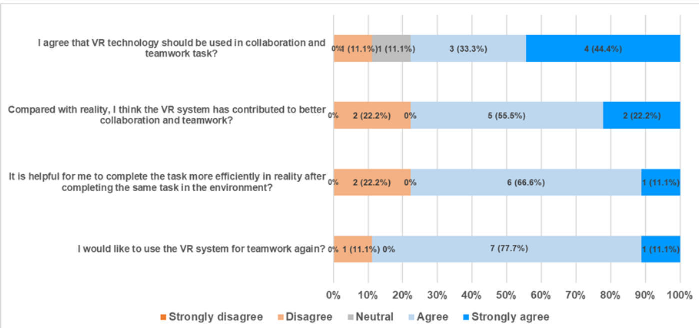


Fig. 4. Responses received from participants regarding their VR experience.

From Figure 4, it can be seen that no less than 77% of participants have a positive attitude toward teamwork applied in VR environments and would like to use the VR system again to cooperate. A similar number of people hold the view that VR is beneficial for team collaboration. Although the analysis of ECG data and survey results led to the consistent conclusion that the majority of people believe they have a better social presence in VR environments, there are still a few dissenting opinions.

IV. Conclusions

This research set out to compare participants' feelings of social presence while playing with teammates a game in both virtual reality (VR) and live, in-person. By analysing data obtained from ECG sensors, we conclude that people feel more relaxed in the VR environment while they would be more stressed in the 'real' in-person state. Moreover, statistical analysis of results from our online surveys suggest that participants playing the VR games were very engaged and pleased with their companions' collaboration. Overall, our study shows that participants preferred to work together in a virtual reality environment. The findings of this study may offer a more solid theoretical foundation for the development of future virtual collaborative projects. However, there are still some improvements that need to be made in the future. Despite ECG sensors being a sound method for measuring stress levels and changes, the results are subject to motion artefacts since the peripheral body is moving. Therefore, collecting more physiological data from other types of sensors could help validate our results.

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