Effects of Sharing Physiological States of Players in Collaborative Virtual Reality Gameplay

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ABSTRACT
Interfaces for collaborative tasks, such as multiplayer games can enable more effective and enjoyable collaboration. However, in these systems the emotional states of the users are often not communicated properly due to their remoteness from one another. In this paper we investigate the effects of showing emotional states of one collaborator to the other during an immersive Virtual Reality (VR) gameplay experience. We created two collaborative immersive VR games that display the real-time heart-rate of one player to the other. The two different games elicited different emotions, one joyous and the other scary. We tested the effects of visualizing heart-rate feedback in comparison with conditions where such a feedback was absent. The games had significant main effects on the overall emotional experience.

ACM Classification Keywords
H.5.1. Multimedia Information Systems: Artificial, augmented, and virtual realities; H.5.1. Multimedia Information Systems: Evaluation/methodology

Author Keywords
Virtual Reality; Empathic Computing; Collaborative Gameplay; Physiological Sensors; Emotions, User Study.

INTRODUCTION
The recent development of low cost consumer head-mounted displays (HMDs) such as the Oculus Rift [17] and HTC VIVE [11], have led to new and diverse ranges of immersive Virtual Reality (VR) experiences. One of the interesting applications of VR is for generating empathy. Referring to VR, Thomas writes "Perhaps the most profound long term applications, however, of such technologies may be as an empathy machine" [30], and goes on to describe how in the future it might be possible for VR to give one person the feeling for what it is like to be someone else. Since then, researchers have shown that VR can be used to create empathy with virtual characters [9, 19], to enable users to feel what is it like to be in a foreign environment, such as a refugee camp [14], or to place the user in the middle of an important news event so they can better understand the experience of people that were there [3].

However, many of these VR experiences are single user, and there has been less research on how VR technology can be used to share the feelings or emotional state of another in real time [20]. Thomas's vision of using VR to give one person the feelings of another has not yet been fully realized.

This paper explores how using a shared viewpoint and simple physiological cue, such as heart-rate, can increase the feeling of connectedness and enhance the experience between a player and observer in a collaborative VR experience. Our study focuses on the effects of sharing heart-rate visualization of the player with an observer and measures both objective and subjective responses of the observer in the presence and absence of such a stimulus. This research will give an insight into types of VR experiences that will yield different emotional responses and therefore diverse collaborative experiences.

To investigate these effects, we have designed two immersive collaborative VR games; one a calm experience of catching butterflies in a field and the other a scary zombie shooting experience. In the two-player experience, one participant was an active player being able to interact with the virtual content, while the other was an observer viewing the VR environment from the position of the active player. We then ran an exploratory user study to measure the effect of displaying the heart-rate feedback of the active player to the observer and compared with a baseline condition where such feedback is not given. Observers subjectively reported that they understood the active player's emotional state more in the presence of heart-rate feedback than when it was absent.

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This work is novel because it is one of the first examples involving sharing of real time physiological data between participants in a collaborative VR experience with the same viewpoint, and the first formative user study conducted with such a system. It is also interesting because it uses an active participant/observer model that may be useful for large-scale shared VR experiences where the view of an active participant is broadcast to many observers. The results will be useful for researchers and developers using VR to create shared experiences and understanding. There is also significant opportunity for future research involving a wider range of emotional and physiological cues, physiological sensing, emotion representation, and collaboration models. The human-computer interaction community, beyond just VR researchers, can use user's emotions as a tool to interact with the interfaces and make the interfaces more empathetic with the user.

The rest of the paper is organized as follows. The next section presents the earlier work on this topic and highlights the contribution of this current study. We follow this by outlining the hardware and software we developed for creating a shared empathetic VR experience. Next we present a detailed description of the user study and the subsequent section presents the results. We then discuss these results and conclude with directions for future research.

RELATED WORK

We have created a collaborative immersive VR game that records real-time heart-rate of one player and displays to the other during the gameplay to communicate the emotional state of the player through physiological cues. However, there are earlier studies in VR that have measured and used various emotions and physiological measures to accomplish different goals. There are also non-VR collaborative systems that show the benefit of sharing physiological data between participants. In this section, we review some of this work that is relevant to our current study, and identify the research gap that we are addressing.

Immersive Virtual Reality has been shown to be capable of triggering emotional responses in users. Felnhofer et al. found that by showing five different kinds of virtual park scenarios, VR environments could accurately trigger emotions [8], using electro-dermal activity (EDA) as one of the objective measures of Presence and emotion. Riva et al. also identified the efficacy of VR in eliciting emotions in human beings, and they noted that degree of Presence experienced in a VR environment has a strong influence on the emotional states experienced [21]. Roy et al. reported that VR environments can elicit emotions and by measuring heart-rate, post-traumatic stress disorder (PTSD) symptoms can be identified [23]. A similar work by Rizzo et al. also argued for the usefulness of VR environments in creating emotional states for military training, particularly in post-war scenarios [22]. Another psychotherapy work by Weiderhold et al. treated people with phobia of flying using VR experiences and measured their heart-rate, skin resistance, and temperature. They found that those treated could fly without taking medicines and were exhibiting physiological states similar to people who were non-phobic [33]. However all of these studies were single-user VR experiences and did not explore sharing emotional cues between participants.

In a collaborative virtual environment users are often represented by virtual characters, and previous research has shown that these characters are capable of eliciting emotional response. For example, Fabri et al. identified the effects of facial expression and body posture of avatars on expressing emotions during communications [7], finding that it is also possible to trigger emotions in the users. A study by Moser et al. reported that facial expression of VR avatars can elicit emotional reactions in the real people observing them [16]. Finally, Fabri et al. showed that people are able to recognize emotion from avatars with a very basic facial animation model [6]. In these studies users shared a virtual environment, and emotion was conveyed between them through virtual face expression. However, the participants did not share the same virtual viewpoint, inhabiting separate virtual bodies rather than the same one, and physiological cues were not captured and shared between participants.

In our research we want to measure emotional state through the use of physiological cues. Previous research has shown that physiological cues can indeed be used to measure emotional state and arousal. For example, Palomba et al. found that heart rate varied in subjects when they were shown a variety of pictures designed to create a strong emotional response [18]. Calvo and D'Mello [2] provide an excellent overview of the various methods for affect detection, including a variety of physiological senses. This builds on an earlier review by Schachter and Singer who provided a summary of the physiological determinants of emotional state [24]. There are also companies such as Sensaura [25] that provide APIs to generate emotional states from real time physiological data.

There are also many examples of researchers using physiological cues to measure stress [5], emotion [34], and Presence [32] in VR settings. For example Mehan et al. [13] created a VR experience where a person could walk to the edge of a deep virtual pit, and measured heart-rate information as an indication of how much Presence people felt in the environment. The more compelling the VR experience, the higher the heart-rate as people walked to the edge of the pitch. Jang et al. [4] have also shown that different virtual environments will generate different physiological responses, and that skin resistance and heart rate variability are reliable physiological measures of arousal in VR. However these environments were all single user experiences and there was no focus on sharing of emotional state.

Finally there are several examples of sharing physiological cues in non-VR collaborative settings. Tan et al. were the first to explore the effect of sharing physiological cues in desktop video conferencing [28]. They found that sharing physiological cues (galvanic skin response, blood pressure, and respiratory rate) between users without video created a higher degree of positive affect than an audio only condition, with no significant difference from a shared video condition without the physiological cues. In a follow-on experiment, with similar physiological sensors, they found that integrating biofeedback showing visual stress can improve remote task collaboration [29]. Finally, a recent work by Willemense et al. found that sharing body warmth virtually between remote collaborators increased the perception of metamorphical warmth but did not elicit any other emotion [35].

This related work shows several important things. First, VR environments can trigger emotions appropriately in individuals, and physiological sensors can be used to measure these emotional states. Virtual Avatars can be used to express emotional state in VR, which can be successfully perceived by other participants in the shared VR experience. Finally, sharing of physiological cues has been used to communicate emotion in non-VR collaborative settings.

These results imply that if showing physiological emotional states can affect human behavior in collaborative interfaces, then VR interfaces could be designed to elicit certain emotions during collaboration. However, there are few studies of the effect of sharing physiological data related to empathy in a collaborative immersive VR experience. To our knowledge, we are the first to use real-time physiological senses (heart-rate) in a collaborative VR gaming environment where both players inhabit the same virtual body and to investigate how multi-player VR gaming experiences can be made more emotionally aware. In the next section, we describe the prototype hardware and software we developed, followed by a description of the user study we conducted.

Figure 1. Participants were asked to stand during the gameplay sessions. They were wearing HTC Vive HMD and two different heart-rate sensors - Empatica E4 and Biometric Glove with Arduino sensors. They were also wearing a Logitech noise canceling headphone to hear the sounds of the game.

SYSTEM

To create collaborative VR experiences, we developed two unique VR games based on our collaborative VR framework and to capture the physiological data, we developed the biometric gloves. This section described these contributions in more details.

Collaborative VR Framework

The collaborative VR framework was developed using Unity3D engine. The motivation behind this development was due to the lack of existing collaborative VR frameworks suitable to our needs. For our study, we needed to be able to customize, share, and synchronize simulation and emotional data between the players. We also needed the observer's head movement to have a dependent positioning but an independent orientation. This allowed the observer to look around freely but bound to the player's position in the VR environment.

To solve these requirements, we designed our framework with a server-client model that synchronizes simulation over the network. The player played the games on the server machine while the observer observed on the client machine. The observer was bound to the player's position so that they always share the same location in the VR scene, however, the observer can look around freely. This setup helped us increase presence, eliminate motion sickness, and allowed the active player and observer to scan the game environment independently and collaborate while standing in the same location. The goal was to create the feeling in the observer that they were inhabiting the virtual body of the player, and so create a greater sense of emotional connectedness. The simulation data and the physiological data of both the player and the observer were streamed and recorded by the system. The simulation data included the time-stamp, head's position, head's orientation, angular differences between player's and observer's gaze direction, and the simulated events tag.

Biometric Gloves

We created biometric gloves to collect physiological data with required sensors attached to it. The glove, which players had to wear (Figure 1), ensured that that the sensors remained in the correct position on the hand. The heart-rate data from the player was collected every second using a Pulsesensor heartbeat sensor running on an Arduino platform [26, 27] from the player's index finger. The data collected by the server was streamed to the client where we showed the heart-rate data using a simple heart icon visualization to the observer (see figure 2(b) and 2(d)). This was a red animated heart symbol that was beating at the same rate as that of the streaming data from the active player. There was also a realistic heartbeat sound played to the observer, matching the detected heart-rate. The active player did not see any heart-rate data, whatsoever.

We also measured the observer's physiological response to seeing the active player's heart-rate. To collect the heart-rate data from the observer, we used a Pulsesensor heartbeat sensor, and an Empatica E4 wristband sensor [12] which was worn by the observer on his/her wrist (See Figure 1). The Empatica E4 can capture high quality heart rate data and stream it to the server over a Bluetooth connection every second. We statistically found that the heart-rate data between Empatica and Pulsesensor do not differ significantly and showed a strong linear regression. However, at times the Arduino sensors collected erroneously high or low values. To mitigate this effect

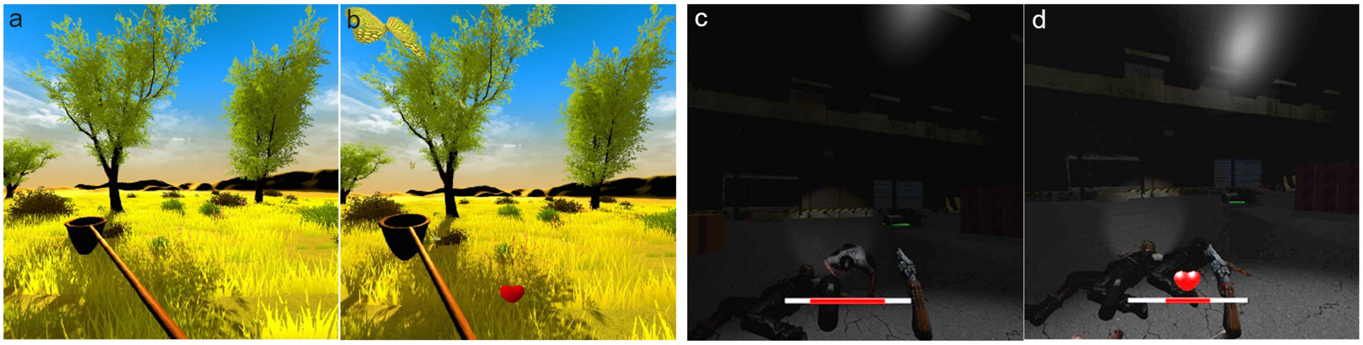


Figure 2. In this user study we used two different games and two different conditions. In our control condition, a heart-rate was not shown to the participants (a) and (c). In the experimental condition, we showed a heart-rate feedback to the participant that showed the real-time heart-rate of the player (b) and (d). (a - b) show the calm butterfly game and (c - d) show the scary zombie game.

we used both sensors at the same time and used the closest value to the corresponding Empatica value at any given timestamp. The readings were fairly consistent and the integrity of the data collected by different sensors was reliable.

Collaborative VR Games

Using our collaborative VR framework we designed two different gaming experiences for the experiment. The first game, "Catch the butterflies", was designed to be an easy and pleasing experience, that should not expose players to a stressful and fearful situation. In this game, the active player was in an open field surrounded by trees and sounds of birds with butterflies flying around them. In one hand they held a net attached to a long stick and the goal was to catch butterflies (see Figure 2(a)). While the game showed how many butterflies were being caught, we didn't explicitly mention that the player should catch as many butterflies as possible. The observer could see the active player's net and if s/he preferred, they could verbally guide the player to catch butterflies. The game lasted for five minutes and the observer was shown the heartbeat of the player (subject to the experimental condition).

The second game, "Shoot the zombies", was designed to be scary, stressful, and more active. In this game, the active player and the observer were placed within a closed dark warehouse (see Figure 2(c)). There were multiple zombies attacking the active player from different angles one after the other, in quick succession. When the zombies could successfully attack the player then we rendered bloodshed and gasping sounds in the VR environment to trigger a feeling pf pain. The player was holding a virtual torch in one hand and a gun in the other. The gun was used to shoot at the zombies to kill them. The observer could see the gun and the torch (and where it was pointing at any given time) and could verbally instruct the active player to look at a certain direction from where a zombie was coming. The instruction was given to the participants to survive as long as possible within this warehouse. The observer would be killed together with the active player after sustaining a certain amount of attacks by the zombies. Both of them were seeing the life bar, but only the observer was seeing the heart rate visualization of the player (subject to the experimental condition). If not killed, this game also lasted for five minutes. However, the game was made so that as long as the active player kept killing zombies and did not intentionally die by stopping to shoot at them, they would not be killed. This was to ensure that the both VR experiences lasted the same amount of time. As expected, in all cases the zombie game lasted for a full five minutes during our user study.

In the next section we report on a user study conducted with these different VR experiences, and then the analysis of the results captured from the user study.

USER STUDY

To evaluate the effects of displaying heart-rate feedback of the active player to the observer, we designed a mixed-factorial experiment with the VR experiences described above, with one between-subjects and one within-subjects independent variable. Figure 2 shows our independent variables.

- Game Experience *(within-subjects)*:
  There were two games in the experiment as mentioned in the above section. The "Catch the Butterflies" game provided a calm and pleasing experience while the "Kill the Zombies" game exposed participants to a scary and stressful experience. All participants experienced both games in a counterbalanced order, with a five minutes interval between the two, which was used to respond to subjective questionnaires.

- Heart Rate Feedback *(between-subjects)*:
  We showed a visualization of the heart rate data of the active player to the observer and not the other way around. The observer was aware of the fact that they are seeing the real-time heart beats of the active player. This heart rate feedback was either shown or not to half of the observers based in which group they belonged to.

As dependent variables we primarily focused on the following qualitative measurements. Subjective feedback after each game session included the Positive and Negative Affect Schedule (PANAS) [31], Inclusion of other in self scale (IOS) [1], and other customized questions based on a four-point Likert-scale. The points on the Likert-scale were very positive, somewhat positive, somewhat negative, and very negative. We intentionally removed the neutral value to force participants to respond either in a positive or negative direction. The PANAS and IOS surveys are well validated surveys of Affect and Empathy respectively. Only the observer was our participant and

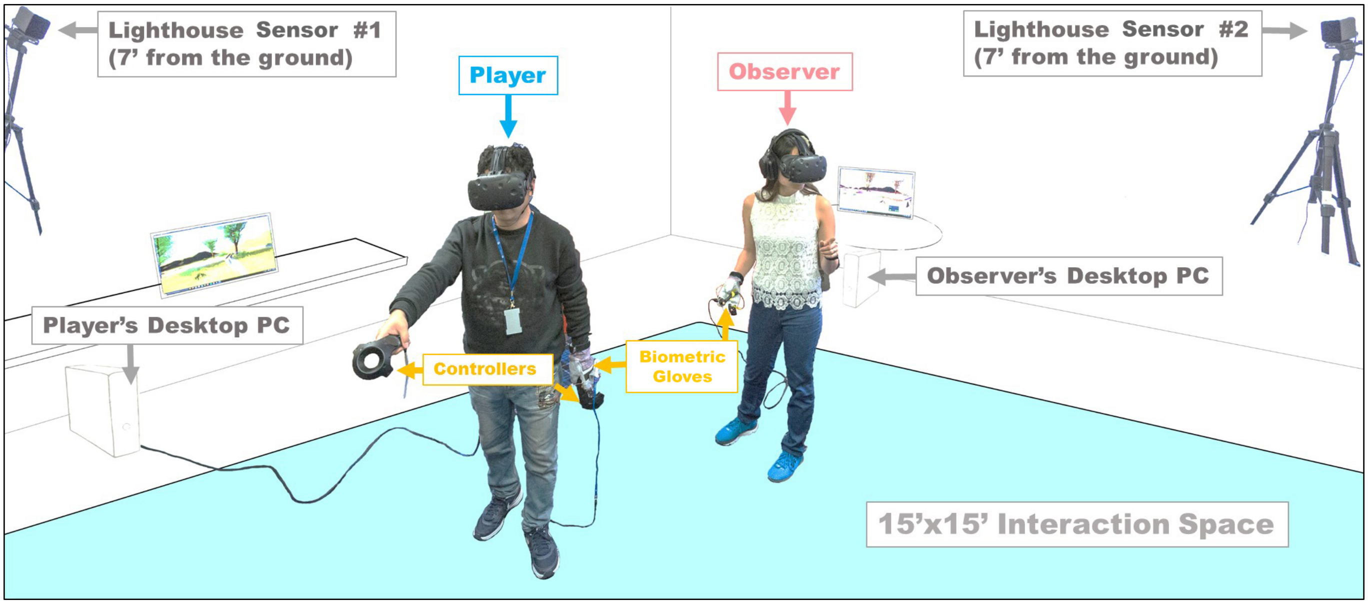


Figure 3. The user study setup. Both player and the observer were standing during the gameplay sessions. They were physically located in a 15' $\times$ 15' calibrated area and could speak to each other to collaborate.

the player, in all sessions, was the same experienced gamer from among the experimenters. By doing so we ensured that all participants received a similar experience in all the games and that the data was not confounded with interpersonal performance differences of the active player. As an objective measure we collected the head orientation of both the player and observer and derived relative head orientation from this data.

Experimental Setup

The essential equipment used for this experiment were as follows:

- 2 $\times$ HTC Vive VR system [11]
- 2 $\times$ desktop PC with Intel Core i7 3.4 GHz, 16 GB RAM, and Nvidia Geforce GTX 950 graphic card
- 2 $\times$ Logitech G933 with Dolby 7.1 surround
- 2 $\times$ Biometric gloves
- 1 $\times$ Empatica E4 wristband

The interaction space was setup to be 15 $\times$ 15 square feet, where the 2 Lighthouse sensors for tracking were placed on tripods at approximately 7 feet from the floor. Both the player and the observer shared the interaction space. The games were optimized for a low specification computer and could run at 90 frames per seconds (fps) on our computers. Both computers were connected to the network through Ethernet and had a minimal latency. The HMD had a vertical field of view (FOV) of 110°, resolution of 2106 $\times$ 1200, and a refresh rate of 90 Hz. The Logitech G933 was a wireless headphone that supported 3D sound to support an immersive VR experience.

Experimental Procedure

We first invited the participants to the experiment room and explained to them the overall experiment and their role in it (see Figure 3). They were introduced to the active player and were asked to sign a consent form. Before beginning the experiment they were offered water to drink and asked to sit and relax for 3 minutes to bring them to a physiologically stable state. At the beginning of the experiment we collected baseline heart-rate data from the participants. To do that, we attached two different heart-rate sensors to their body; an Empatica E4 on their dominant hand's wrist, and one Arduino sensor to each of their hands' index fingers. They wore the Vive display and headphones, and were shown a 360° immersive static image of a mountain. They were sitting on a rotating chair and could rotate themselves as preferred. During this phase, we first did not show any heart-rate data for 90 seconds and then we showed pre-recorded heart-rate data for another 90 seconds without any interval between the two. It helped us measure participants' baseline heart-rate in both situations.

They were then asked to take a break for about 2-3 minutes. After that, they were exposed to the games in a counterbalanced order. During the gameplay sessions the Empatica E4 wristband was removed and attached to active player to collect his heart rate data and display in the game to the observer, while the two Arduino sensors were kept attached to the observer. During the session the participant was asked to stand, as the active player was also standing to play the game. The participant and active player were in the same room, but could not see each other due to HMDs they were wearing, however they could talk freely to one another if they desired. After the first gameplay session, participants were asked to fill out the subjective questionnaires and wait for 5 minutes before the next session. The second gameplay session was the same as the first session but with a different game. Participants again filled out the same set of questionnaires after the second session as well. This ended the experimental sessions. We thanked the participants with refreshments and they were al-

	Male		Female	
Condition	*Count*	*Age*	*Count*	*Age*
Experimental (HR)	9	32.1 (3.8)	4	30.3 (3.8)
Control (NoHR)	10	30.2 (6.7)	3	27 (4.4)
Overall	19	31.1 (5.5)	7	28.9 (4.1)

Table 1. Participant demographic data: their count and mean age (standard deviation) in years for each group. The experimental group was shown a heart-rate feedback during the gameplay and the control group did not see that feedback.

lowed to leave the venue. Overall, the experiment took about 45-60 minutes for each participant.

Participants

We recruited a total of 26 participants (13 in each group), as shown in Table 1. Participants were healthy adults without any physical, mental, or visual impairment. Their ages ranged between 22 and 41 years (M=30.5, SD=5.2). Six of the participants had never experienced an HMD, 15 of them had little to moderate experience, and five of them were very experienced with HMDs. Seven of them had previous experience with immersive VR games. Eleven of them were regular gamers and 13 had moderate gaming experience.

Hypotheses

We had five hypotheses for this experiment before beginning.

- **H1**: Displaying heart-rate feedback will enhance correlation between the observer's and active player's heart rate more than when this feedback was not given.
- **H2**: The heart-rate will show the physiological state of the player, which is very personal, so we expected subjectively, the observers will feel more connected to the active player when heart-rate feedback is shown than when it is not shown.
- **H3**: As the scary game requires constant killing of zombies to stay alive in the virtual environment and only the player can kill zombies, so we expected that the scary game will trigger more subjective understanding of emotions between the observer and active player than the calm game.
- **H4**: Heart-rate feedback will provide a constant reminder to the observer that another person exists in the environment, so we expected showing heart-rate feedback will result in more positive affect than when it is not shown.
- **H5**: For the same reason as H4, we expected showing heart-rate feedback will result in more interaction between the observer and active player than when it is not shown.

RESULTS

To analyze the data we first looked at the subjective responses and the PANAS data. Next, we analyzed the heart-rate feedback during the gameplay. Finally, we also investigated the relationships between the player's and the viewer's head movement during the gameplay. We also qualitatively analyzed the viewer's actions and feedback.

Condition	*Baseline*	*Butterfly*	*Zombie*
HR	86.7 (15.1)	99 (15.6)	112.4 (11.7)
NoHR	79.1 (3.4)	104.5 (7.2)	106.1 (13.8)
Overall	83.1 (11.6)	101.6 (12.3)	109.4 (12.6)

Table 2. Mean (± 1 standard deviation) of heart-rate data collected during three stages.

Condition	*Game*	*Q1*	*Q2*	*Q3*
HR	Butterfly	2.4 (.2)	1.5 (.2)	1.9 (.2)
	Zombie	1.6 (.2)	1.0 (0)	1.7 (.2)
NoHR	Butterfly	2.8 (.3)	1.7 (.2)	2.2 (.3)
	Zombie	2.1 (.2)	1.2 (.1)	1.9 (.2)

Table 3. Mean (± 1 standard error) of subjective questions. Lower numbers indicate better results.

Overall, we found the type of game experience had a significant effect on almost all dependent variables. The visualization of heart-rate feedback showed a slightly more, yet non-significant, positive affect than in the control condition, where a heart-rate feedback was not present. Due to only 13 participants in each group, we did not observe a sufficiently high power in statistical tests for heart-rate feedback analyses. These results are described in more detail in the rest of this section.

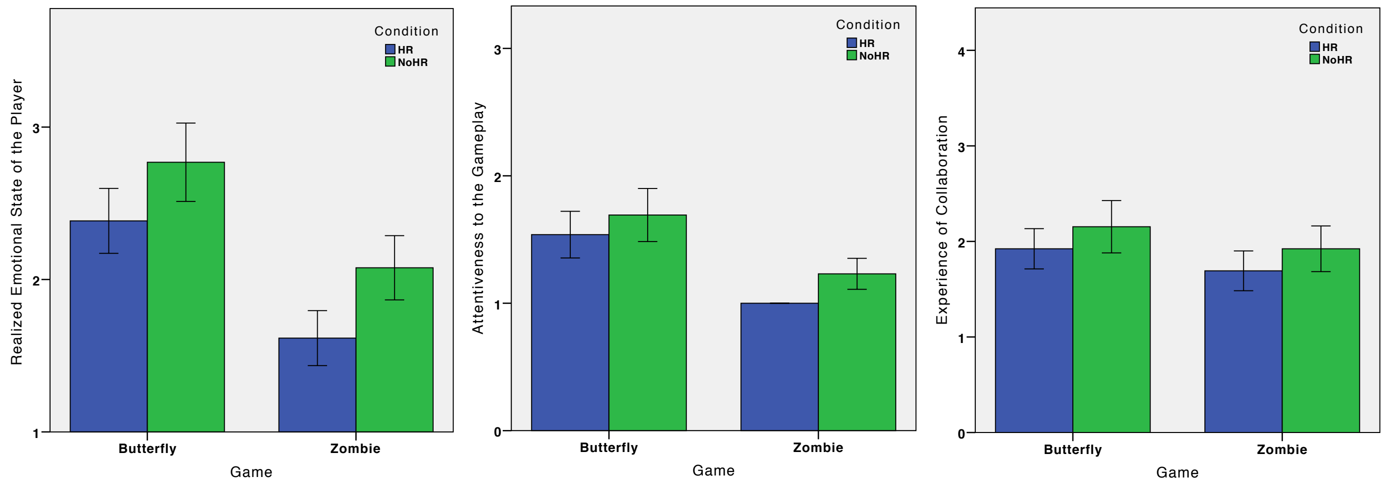
Baseline and In-Session Heart-Rate Data

We collected heart-rate data three times. First, before starting the experiment we collected a baseline data, then we collected heart-rate during both gameplay sessions. Table 2 shows that there was no significant difference between the control and experimental conditions for any of the games. As expected, the heart-rate significantly—$F(2, 26)=20.53$, $p < .001$, $\eta_p^2 = .61$, $o.p. = 1.0$—increased during both of the gaming sessions from baseline as during the gameplay participants had to stand and, when preferred, to actively collaborate. The zombie game produced a higher average heart-rate than the butterfly game, which is a consequence of the scary experience in the former. However the difference was not significant. Interestingly, the increase in average heart-rate from the butterfly game to the zombie game was more in the case of experimental condition. However, this interaction was also not significant.

Subjective Questionnaire

Analysis of subjective feedback showed a preference for the heart-rate visualization, although the differences were not significant between the experimental and control groups for any of the subjective questions with the number of participants in our study (see Table 3). Further studies are needed to make a conclusive claim about this effect.

We analyzed the results by executing a mixed-factorial ANOVA, but we did not notice a significant effect of heart-rate visualization on subjective feedback. However, the different games did have a significant effect on two subjective questions. Participants felt that they realized the emotional state of the player more in the case of the Zombie game (M=1.85,



(a) (b) (c)

Figure 4. Subjective feedback on three question. 4(a) how much did participants understood the emotional state of the player? 4(b) how much were they attentive to the gameplay? 4(c) how much did enjoy the collaboration? Lower values indicate better outcome and whiskers represent ± 1 SE.

	Positive Affect			Negative Affect			IOS Scale		
Condition	*Butterfly*	*Zombie*	*Overall*	*Butterfly*	*Zombie*	*Overall*	*Butterfly*	*Zombie*	*Overall*
HR	30.9 (2.1)	33.7 (2)	32.3 (1.5)	13.1 (1)	17.8 (2)	15.4 (1.2)	3.5 (0.5)	4.6 (0.5)	4.0 (0.4)
NoHR	25.8 (2.7)	29.7 (2.4)	27.7 (1.8)	12.8 (0.6)	18.1 (1.6)	15.4 (1)	3.6 (0.6)	4.8 (0.5)	4.2 (0.4)

Table 4. Subjective feedback on PANAS and IOS scales.

SD=.73)—F(1, 24) = 25.48, $p < .001$, $\eta_p^2 = .52$, $o.p. = .99$—than in the Butterfly game (M=2.58, SD=.86). This finding satisfies our hypothesis H3. Similarly, participants reported to be significantly—F(1,24) = 14.9, $p = .001$, $\eta_p^2 = .38$, $o.p. =$ .96—more attentive during the gameplay in the case of the Zombie game (M=1.12, SD=.33) than the Butterfly game (M=1.62, SD=.7). We didn't find any significant difference between their experiences of collaboration (see Figure 4).

Positive and Negative Affect Schedule (PANAS)

The PANAS scale measures 20 different emotions and feelings categorized into positive and negative affect. Overall, there was more positive affect than negative affect (see Figure 5).

For positive affect, we found a significant main effect of games F(1,24) = 7.41, $p = .01$, $\eta_p^2 = .24$, $o.p. = .74$. The Zombie game (M=31.7, SD=8.1) resulted in more positive affect than the Butterfly game (M=28.3, SD=8.9). The experimental condition consistently showed more positive affect than the control condition but the difference was not statistically significant—F(1,24) = 2.27, $p = .15$, $\eta_p^2 = .09$, $o.p. = .3$)—with the number of participants in our study. However, the standard error of means indicates that the means have a slim chance to overlap and the difference will hold (see Table 4).

Similarly, for negative affect, the presence of heart-rate feedback during gameplay did not make any difference. However, we noticed a significant main effect of Game—F(1,24) = 19.4, $p < .001$, $\eta_p^2 = .45$, $o.p. = .99$. The zombie game (M=17.9, SD=6.3) caused more negative affect than the butterfly game (M=12.9, SD=2.9).

Relative Gaze Direction

We analyzed the relative difference in the viewing angle of the player and the observer at each frame. This data was an indicator of where the observer was looking at during the gameplay at any given point in time in respect to the player's gaze direction. We normalized the data based on the player's view direction. The data interestingly shows that there was a main effect of game observer's viewing behavior. Overall, in the butterfly game (M=49.76, SD=9.41) the difference between player's and observer's gaze direction was significantly less than the zombie game (M=71.05, SD=11.6)—F(1,22) = 81.57, p<.001, $\eta_p^2 = .79$, $o.p. = 1.0$ (see Figure 6). However, there was no significant difference between the experimental and control conditions. We removed data of first two participants due to technical error in recording of the data.

A more detailed analysis, as shown in Figure 7, demonstrated an interesting pattern difference between the two games. In the butterfly game, the observer almost always aligned his/her view with the player, whereas in the zombie game they looked at a different angle, probably to complement the users view direction or due the fear of being attacked and identifying potential threats.

General Observations and Interviews

During the experiment while the one of the experimenter was playing the game, another experimenter was observing the par-

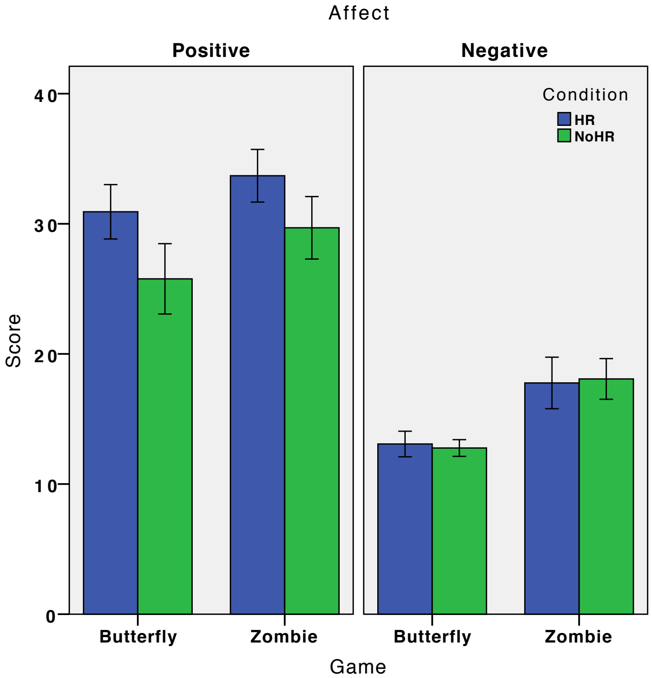


Figure 5. Analysis of PANAS data showed an evidence of non-significantly more positive affect in the presence of heart-rate feedback. Zombie game caused higher positive and negative affect than the Butterfly game.

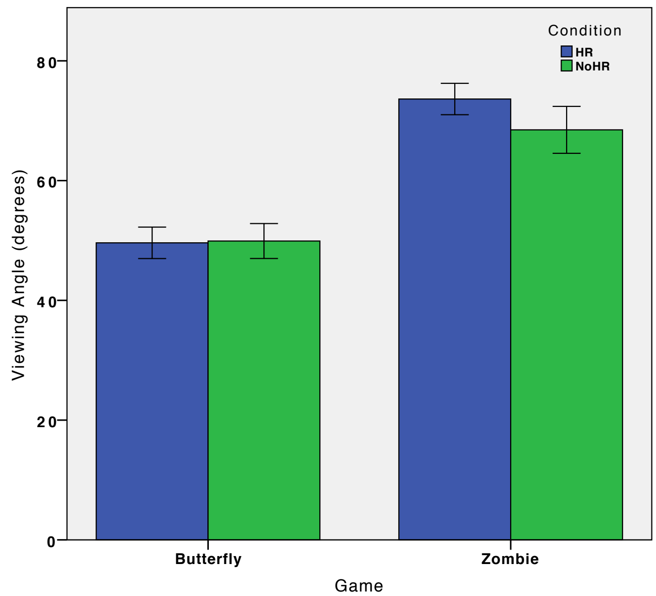


Figure 6. Analysis of viewing angle shows that the butterfly game had significantly less difference in viewing angle between the observer and the player than the zombie game. Whiskers represent ± 1 standard error.

ticipants and taking notes about their actions and expressions, which we qualitatively analyzed.

First, in the butterfly game, participants were moving slowly in the physical space and communicated less with the player. Participants were mostly in relaxed postures and did not express any feeling of anxiety or fear. They did not express extreme joy either except for mentioning the environment to be "cool" or "nice". One participant (P5) reported that all the butterflies looked the same and there were multiple of them in any direction, so it was hard for her to point to any particular butterfly and instruct the player to catch it. Two of the participants said that they thought the player was performing well and did not feel a need to instruct the player. There was no noticeable difference between behaviors in the presence or absence of the heart-rate feedback. Second, in the zombie game, participants moved randomly in search of zombies and tried to follow the direction of the sound. A few participants expressed fear by screaming and moving backwards when the zombie came too close or attacked the player. Overall, participants communicated more with the player in this game than in the butterfly game. However, there were a few participants who did not communicate. As reasons, one of them said he was enjoying the environment and the two other mentioned that they thought the player could not hear them. We noticed that having a heart-rate feedback increased communication in this game, although we did not measure it objectively.

DISCUSSION

This is one of the first studies that has explored the effect of sharing a visualization of real-time heart-rate of a player to another in a collaborative VR gameplay session, where both players share the same position in the virtual environment. Two different gaming experiences—joyous and scary—in this study elicited two different kinds of emotion in participants. Our data showed a significant main effect of gaming experience for all dependent variables. However, we did not find a significant effect of the heart-rate visualization, although, there was a non-significant indication that visualizing the heart-rate resulted in more positive affect and created more subjective connections between the collaborators in these gameplay sessions. As such, except for H3, none of the other hypotheses were satisfied.

We believe, agreeing with other earlier work [21, 8], that immersive VR experiences elicit influential emotions by themselves and our way of visualizing heart-rate feedback was not effective enough to significantly override that experience. At the same time, the number of participants was only 13 in each condition, which did not result in a significant difference, although the standard errors indicate a large difference between experimental and control conditions. The games, on the other hand, did trigger significantly different subjective and objective behaviors. Hence, it could be argued that in a collaborative gaming environment the experience of the game has higher influence on human behavior than subtle cues such as heart-rate of a co-player. We should note that most of the participants during the post-study interview mentioned that the heart-rate feedback was helpful for them to understand the other player's emotional state and they also felt more connection with the player. We believe this preference was represented in the positive affect schedule, although non-significantly.

We noticed, in both conditions, that a few participants did not interact with the player at all. During the post study interview two main reasons for that became apparent. First, the partic-

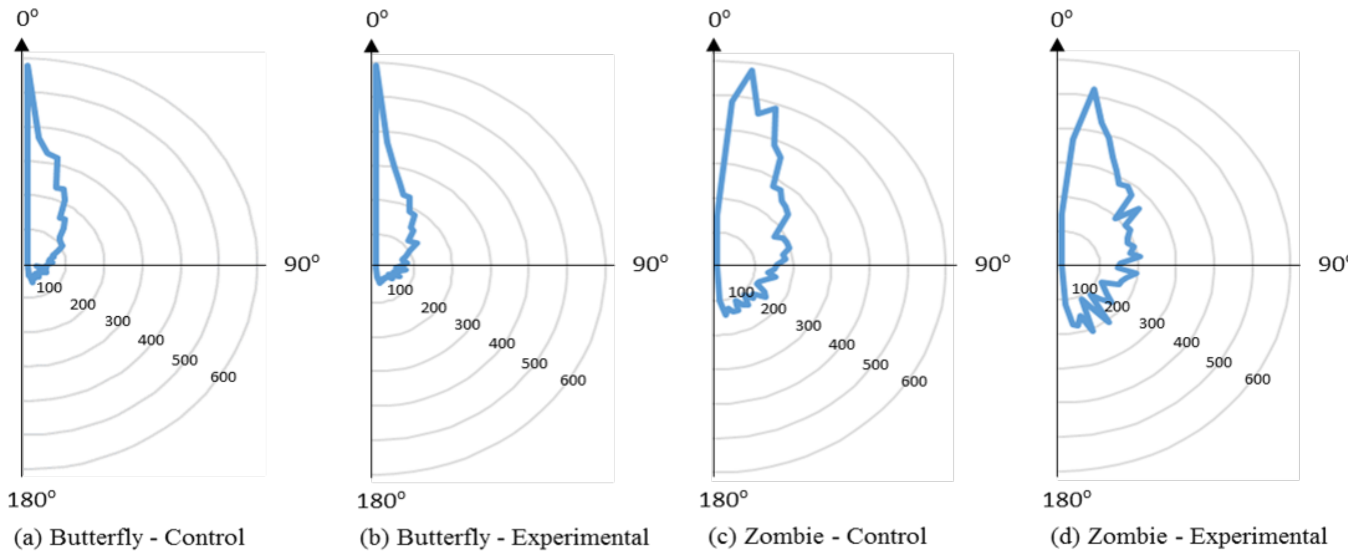


Figure 7. Observers looked differently in the butterfly game than in the zombie game. Their gaze direction was more aligned to the player in the butterfly game but in the zombie game the direction was less aligned. 0° shows the normalized direction of player's gaze.

ipants were experiencing the game as a movie, and did not think their collaboration could influence the player's performance. One female participant (P2) mentioned that *"I knew I am not going to die in real and I was enjoying the game as a movie!"* Second, they were not sure if the player could listen to them or not, although we mentioned to them that they could collaborate with the player if they preferred and that he could hear you. For an example, a male participant (P20) noted that *"I guessed you had a noise-canceling headphone on ... I was not sure if you could hear my voice"*.

Another important feedback from the participants was their inability to understand where the player was actually looking at, at any point in time. Some of them were confused about the player's gaze direction, while, others mentioned that they assumed that the player's gaze was in line with the net (in the butterfly game) and the flashlight (in the zombie game). The same participant P20 mentioned *"I had absolutely no clue where you were looking at. For some time I tried to follow your gun, but later I realized you were moving the flashlight a lot"*. We believe that in such collaborative gaming experiences it could be important to provide a cue of the players' physical orientation to each other. This could be achieved by adding a virtual viewpoint visualization of the player's viewpoint. This would be a good direction for future research.

Cognitive psychology may also suggest real or perceived differences between participants in the study. As previously noted, there were differences between participants with their level of interaction with the player and understanding of their emotion when shown the heart rate. We postulate, that this could due to differences in personality. The Myers Briggs Type Indicator (MBTI) is an instrument used that loosely categorizes people as thinking or feeling types [15]. So, feeling types tend to be more empathic, experiencing others' feelings and emotions as though it is their own. In contrast, thinking types are less likely to be impacted by the real or perceived emotional state of others. As such, the effectiveness of visualizing the heart-rate could possibly be dependent on the personality type of the observer. In our study, we did not test for this personality type as a screening process. We believe that adding a personality test based on the MBTI and sorting participants into appropriate groups could yield different results between the groups, as it was suggested by Howe and Sharkey [10]. As such, we postulate that visualizing the heart-rate in a collaborative VR environment could produce stronger results for people who are identified as feeling types.

LIMITATIONS

This is one of the earliest explorations of shared emotional cues in immersive VR multi-player gaming environments. Our prototype and the user study had some limitations, which we want to address in future research.

First, the games we developed elicited two different emotions. However, there are several other emotions that were not investigated in this study. Accordingly, the results cannot be generalized for all immersive VR experiences. Further studies are needed to investigate this effect on all different emotions.

Second, the heart-rate recording devices, both Empatica E4 and Pulsesensor, are not as accurate as medical grade sensors. In particular, when the hands on which they are worn are in motion, the data collection is noisy. We will further investigate new sensor technologies and compare them with medical grade sensors for accuracy in both static and moving conditions.

Third, the number of participants recruited in this study (13 in each group) did not result in sufficiently high statistical power for the analysis of the between-subjects factor (heart-rate feedback), although it was enough to analyze the within-subjects factor (game experiences) with sufficient statistical power (> 0.8). Extending the study with more participants would enhance the statistical power.

Finally, as mentioned in the earlier section, we did not screen participants based on their personality types using tools such as MBTI. Hence, we cannot analyze whether the study was confounded with personality types or not. In future studies, we will consider personality types and create groups accordingly.

CONCLUSION AND FUTURE WORK

Our primary motivation of this research was to explore how using a shared viewpoint and simple physiological cue, such as heart-rate, can increase the feeling of connectedness and enhance the experience between a player and observer in a collaborative VR experience. For this investigation, we created our own software and hardware prototypes. We performed an exploratory user study using these prototypes. We were able to understand the effects of such visualizations during collaboration and identified new directions of further research.

In this paper, we have presented for the first time, an immersive collaborative VR experience where multiple players can co-locate and have different head orientation with an added physiological cue of heart-rate. The motivation of such an interface was to be able to portray one player's emotional state to the other and create a better collaborative experience and have a deeper understanding of how their partner is feeling.

Based on this exploratory study, we found that the gaming experiences had a strong influence over the heart-rate cue. However, heart-rate was overall preferred subjectively, but the effect was not significant and yielded low statistical power with the current setup and the number of participants.

Game-design Guidelines

We have received several valuable insights from this study, which could be useful for future collaborative game designs in VR. We would like to follow these guidelines in our future VR game design.

- **Gaze direction feedback**: Observers reported that they couldn't exactly locate where the players was looking at any point in time. We suggest that in this type of games a cue to the players' gaze direction would be helpful for better user experience.
- **Voice communication**: In our study, both the player and the observers were collocated in the same physical space. However, in other cases they may be located remotely. Also, most VR games require a headphone to be worn by the players for better better sound effects. Several participants reported that they assumed the player could not hear their voice. As such, to enable efficient communication between the collaborators it will be appropriate to add microphone support in the games so that players can clearly talk to each other.
- **Visualization of emotional cues**: We showed the visualization of the heart-beat at the bottom of the screen and did not change its appearance. As the VR games are extremely engaging, observers remain focused on the game and ignore other subtle cues. We suggest to visualize the emotional feedback in more salient way to attract attention, although care needs to be taken to avoid distracting the players from the game.
- **Interaction for observers**: A few observers complained about their inability to interact or play the game and reported that they lost interest. In games where one player takes the main playing role and the other remains an observer, it will be important to keep the observer interested in the game. We suggest one way to keep the observer interested is to enable interaction with the game in some way.

Overall, our contributions are threefold. First, we created both software and hardware prototypes to make shared viewpoint immersive VR gaming possible with physiological data collection and sharing (as emotional cues). Second, for the first time, we explored the effect of such emotional cue sharing on the user experience. Third, we presented design guidelines for collaborative VR games based on participant feedback. We believe our early exploration of using emotional cues shows the promise of such interfaces and opens new research directions that could make collaboration in VR more personal and empathetic.

We noticed that the heart-rate feedback generated non-significantly more positive affect than the condition without the heart-rate. In the future, we would like to investigate different ways of visualizing heart-rate information and representing emotion between users. Here, we only used heart-rate as a physiological cue to inform about the emotional state of the player. In future studies, we would use other physiological and emotional cues such as EDA and facial expressions and evaluate their effect on the gaming experience. Another important direction of research is to make a gaming experience where both players can equally participate in the game and complement each other. At the same time showing emotional states to each other. It will also be interesting to identify the effect of such visualizations on different groups of people as identified by MBTI, and potentially change the visualizations to match the user's personality type.

Here we only used a scary and a calm gaming experience. However, there are many other immersive experiences in VR where this emotional feedback can have a different impact. For example, in a horror gaming experience the sense of belonging with another person and being able to understand his/her physiological state may influence the experience of the other person. By understanding these effects in more detail, we will be able to control and modulate the experience of the collaborators artificially and adaptively.

Beyond gaming in VR environments, we are also interested to investigate the effects of sharing emotional cues in different collaborative application domains. For example, teaching and learning, performing collaborative tasks in augmented reality, remote meetings and interviews etc.

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