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Fear as a Biofeedback Game Mechanic in Virtual Reality: Effects on Engagement and Perceived Usability

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ABSTRACT

Virtual Reality (VR) is now an affordable technology that is starting to penetrate the mass market. Providing accessible solutions to enhance VR experiences is crucial. In this paper, we consider a wearable solution as a mean of interaction in VR, to add a biofeedback mechanic. We hypothesized that the use of a biofeedback loop in a VR experience can enhance user engagement. We created a physiologically enhanced horror game coupled with a heart rate monitor smart wristband. We evaluated the players' engagement with and without biofeedback. We observed a high interest of the participants for biofeedback and highlighted higher engagement when the biofeedback mechanic was fully integrated in the experience.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **User centered design**;

KEYWORDS

Virtual Reality; Physiological Sensors; Emotions; User Study.

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1 INTRODUCTION AND RELATED WORK

In virtual reality User Experience includes diverse factors: immersion [4, 23], presence [5, 15], engagement [19], emotion, skill, and more [24]. Considering these aspects and the vast literature on the topic, we focus on the notion of engagement, a central component to the VR experience. O'Brien et al. [19] developed a conceptual framework to define User Engagement with technology. They characterized engagement as "*a quality of user experience characterized by attributes of challenge, positive affect, endurability, aesthetic and sensory appeal, attention, feedback, variety/novelty, interactivity and perceived user control*". The work of Hassenzahl et al. [11] points toward similar simpler conclusions, as they divide engagement in two main categories pragmatic qualities (usefulness and usability of the system) and hedonistic qualities (motivation, stimulation and challenge for the user). From those works derived multiple scales to measure user engagement in games and human-computer interaction systems [20, 25]. Lessiter et al. [12] define presence as multimodal, composed of numerous factors, each one a lever to work with. They specifically highlight the mutual influence between presence and engagement, by reporting a four-factor solution for presence: physical space, engagement, naturalness and a fourth attenuating factor, negative effects.

Bouvier [5], like Geslin [10] more recently, defends the idea of a link between presence and emotion and explain that the feeling of presence can only last if the experience is sustainably carrying emotions. This is supported by multiple studies, like the one of Price and Anderson [21] which demonstrates that a simple emotion inducing environment (e.g., joy, sadness) positively affects the feeling of presence. Baños et al. [3] and Riva et al. [22] reach similar conclusions.

The contributions of these studies reside in the capacity to induce emotions via a virtual environment and knowing how much these will allow the user to be more invested in what he is experiencing, to have control over the "Flow" (defined by Csíkszentmiahályi [7] as "*the mental state of operation in which a person performing an activity is fully immersed in a feeling of energized focus, full involvement, and enjoyment in the process of the activity.*").

One of the possible solutions to create this "flow-perfect" environment would be to induce emotions in real time depending on multiple physiological data recordings of the user. This would allow to adapt the presence and emotion inducing schema depending on the personality and the goals of each user. In Virtual Reality, researchers are studying the correlation between users emotional personality, their autonomic nervous system (or ANS) activity level

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and the adaptivity of the virtual environment [6]. Other studies are conducted in games, aiming to measure players' physiological data to enhance the gaming experience [2, 13], in particular VALVe studio's laboratory [1]. Some studies also experimented the usage of biofeedback to produce new gaming mechanics in video games [8, 16, 17] by changing for example the speed of the avatar depending on the respiration rate or by changing the in-game weather. Results of these studies shows that the participants appreciated the physiologically augmented versions of the games, recognizing that the biofeedback can enhance engagement and user experience in computer video games.

Dey et al. [9] more recently used physiology and VR to share emotional states between players and see how empathy affected user experience. By sharing physiological states and thus emotions between players in VR, they tried to study how it affected players' behavior in collaborative interfaces. The results of their study highlight that the participants felt more empathy toward the other player and were more involved, communicated more during the game when they could see the other player's heart rate.

In the light of our bibliographical study we note the high potential of the integration of a biofeedback loop in VR to enhance user experience. It is important to study new interaction mechanics for affordable virtual reality. In this study we investigate the interest of a biofeedback loop in regards to player engagement in virtual reality. The goal being to better understand these new game mechanics design.

2 SYSTEM

To study the effect of the biofeedback loop we created a physiologically enhanced VR horror game, developed on the Unity 5 game engine. This section details the setup and applications developed.

The equipments used for this experiment were a HTC Vive VR system, a desktop PC (Intel Xeon E5-1603, 8GB RAM and Nvidia Geforce GTX 1060 graphics card), a Mio LINK heart rate wristband and a headset. The navigation space was set up to be 3 x 3 square meters. For the physiological aspect we used the Mio LINK, a smart wristband capable of measuring heart rate. Heart rate allows us to estimate the user's psychophysiological state to interpret some basic emotions.

2.1 VR Game

The goal of the experience is to induce fear to the user, one of the simplest emotion to induce [9]. Lobel et al. [14] also demonstrated the interest of horror biofeedback enhanced games for research on psycho-physiological studies. To do so we developed a Victorian era inspired immersive environment (like the game *Dishonored 2*[1]). The experience takes place in one room of a manor, that match the tracking zone of the Vive. We choose to lock the player in a confined space in order to enhance the frightening effect. The main room overlooks two adjacent rooms and a staircase. It is furnished with a chimney, a candelabrum and a chandelier to enlighten the place. The sound design of the game is also part of the anxiety inducing process. A music box placed above the chimney will play music throughout the game. Moreover spatialized step noises, crackle of embers and creaking of doors and windows punctuate the experience to add up to the anxiety-provoking atmosphere.

To create an engaging experience we added a goal to reach, the participant has to delay the arrival of a creature attracted by noise (represented by a typical horror genre "little girl"). The creature can appear randomly from each entrance to the main room (two adjacent rooms and a staircase). To keep it away, the participant must limit the amount of noise by closing the doors and the music box, those opening randomly repetitively during the experience. When the creature appears she slowly walks toward the player. The closer she gets the faster she goes, going on all fours before rushing towards the player. The player is equipped with a flashlight to illuminate the creature to make her disappear. If he/she can't, then the game ends as the creature attacks. If he/she does succeed, then the creature disappears temporarily and comes back if there is too much noise again. After a quick tutorial phase, night falls, if the participant survives for five minutes during the night then the sun rises and the game ends.

2.2 Influence of the physiological data

2.2.1 Calibration. To estimate the psychophysiological state of a participant we analyze the evolution of physiological data compared to his/her resting estimate. To determine a user's resting heart rate value we based our solution on the works of Nogueira et al. [18] and Dekker and Champion [8]. We record a user's heart rate values for a 2 minutes and 30 seconds period (150 recorded values of BPM). Each participant listen to the music "*Union's Weightless*" during that period (seated for 1 minute 15 then stand up for 1 minute 15 as the heart rate being able to vary between the two positions). A mean value of the 150 recordings is then computed to determine the participant's resting heart rate.

2.2.2 Biofeedback. To study the effect of biofeedback on user experience, heart rate data, monitored by the Mio smart wearable, influenced different elements of the game. When the heart rate increases significantly (15 BPM over the calibrated value), the light emitted by the chimney will diminish and the opening frequency of the doors and the music box will increase. When the user's heart rate reach a value superior to 20 BPM compared to the calibrated value (this value was determined after preliminary user tests) the user hears a heart beating faintly. If he/she reaches 30 BPM more than the calibrated value then the heart beat sound is faster and louder. The user's field of view starts reducing if his/her heart rate is higher than 40 BPM compared to the calibrated value. It can become completely obstructed, leaving the user in the dark. If the value of the participant's heart rate goes below these thresholds and closer to the calibrated value then the modified elements return to their regular functioning, encouraging the user to keep calm to reduce the difficulty of the game.

3 USER STUDY

3.1 Variables and measures

The presence of biofeedback is used as an independent variable. The experiment will be conducted following a between-subject design:

- No biofeedback: the game is not enhanced by the physiological loop.

[1]Arkane Studios - https://dishonored.bethesda.net - 2016

- Active biofeedback: the game is enhanced by the user heart rate, causing changes in the game's mechanics and environment.

The dependent variables are the duration of the experience and its completion, participants post experience feedback on perceived usability, involvement and focused attention and heart rate recording.

To obtain the participants feedback on the experience we built a questionnaire. Based on the *Presence Questionnaire* of Witmer and Singer [26] and the *User Engagement Scale* from Wiebe et al. [25] (see Table 1). Most of the answers are based on five points Likert scales, some are open questions and multiple choices questions.

Participants experienced each version of the game to have them answer questions comparing the two experiences (which one did they prefer and how were they different). But to avoid any bias due to the importance of the fear effect, we decided to register involvement, the perceived usability and focused attention only after the first round. After experiencing the biofeedback version of the game (first or second round), the participants also answered questions about its use and what it brought to the experience.

ID	Question
PU1	How much could you do the tasks needed during the game?
PU2	How responsive was the environment to the actions that you initiated (or performed)?
PU3	How mentally taxing were the game mechanics?
PU4	How confusing to use were the game mechanics?
PU5	How much did you feel frustrated during the game?
PU6	How demanding was the experience?
FI1	How drawn were you into the gaming tasks?
FI2	How completely were all of your senses engaged?
FI3	How involved were you in the virtual environment experience?
FI4	How fun was the gaming experience?
FI5	How frightening did you feel the experience was?
FA1	How long did you feel the game lasted?
FA2	How much did you pay attention to the real world during the experience?

Table 1: Questionnaire with 3 dimensions: Perceived Usability (PU), Felt Involvement (FI), Focused Attention (FA).

3.2 Experimental procedure

First the participants are asked to read the consent form and another one asking if they had no heart problems and knew the risks of VR. If they accept and sign the forms we make them proceed to the pre-experimentation questionnaire, to collect information about their profile (age, gender, experience with VR and video games, sensitivity to motion sickness).

Participants are equipped with the wristband. If they start in the active biofeedback condition (BF), we proceed to start the calibration phase. Then they put on the Head-Mounted Display (HMD) and we explain to them that their heart rate will be used in the experience, the more they are afraid the harder the game will get. They are also told that they can remove the HMD at any point if they don't feel comfortable. They are then told about a voice over giving them the game's instructions and that once they are done listening to it they proceed to start the experience. The procedure is the same for those who start in the non active biofeedback condition (NBF) except we don't perform the calibration phase and don't inform them about the usage of heart rate.

We purposefully did not give the participants methods on how to lower their physiological response, in order to evaluate the players spontaneous capacity facing the game mechanics (as it could be implemented directly for entertainment experiences).

Once they complete the first round, the participants are given time to get their heart rate back to a resting state and also answer the questionnaire. If they are part of the BF group they also answer questions about the usage of biofeedback.

After the questionnaire they gear up again to redo the experience in the opposite condition. Finally, they answer the comparison questions and we conduce a semi-structured interview to collect subjective evaluations of what they've experienced. Overall the total experiment lasted for about 40 to 50 minutes for each participant.

3.3 Participants

We recruited 32 participants (9 women and 23 men), aged between 21 and 44 (M=25.3, SD=5.5), all of them are experienced in VR. On the question "How experienced are you with Virtual Reality", on a Likert scale ranging from 1 ("No experience") to 5 ("It's my working tool") the mean score was 4.06 (SD=0.84). We purposely selected people familiar with VR as to avoid them being more focused on discovering the device than living the experience. 17 of them started in the NBF condition and 15 started in the BF condition. Of the participants, only 2 reported never playing video games, 5 play from time to time, 6 regularly and 19 are hardcore players.

3.4 Hypotheses

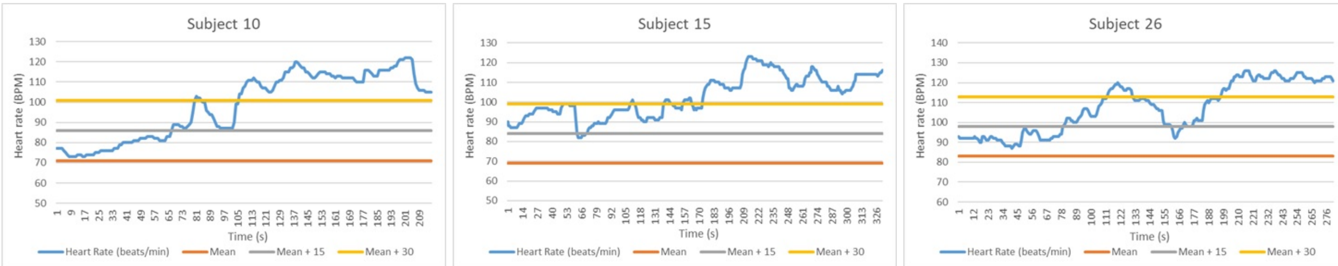
- H1: The users are capable of influencing their own heart rate in game.
- H2: The addition of the biofeedback loop modulates the game difficulty making it more challenging to master.
- H3: The introduction of a biofeedback loop, with the heart rate, enhances user engagement.

4 RESULTS

We first looked into the heart rate control. We then looked at the answers of our questionnaire, completion time and finally the subjective judgments and preferences. For the questionnaire's answers the Shapiro-Wilk test demonstrated the non normality of their distributions, we then performed Mann-Whitney tests.

To see how possible it was to "influence" one's own physiological state in order to comply with the game mechanics, we qualitatively observed the heart rate control the users had and compared it to their own feeling about their control. These results are described more in detail in the rest of this section.

Of the 32 participants, 19 reported trying to influence their own heart rate during their session with biofeedback (11 once or twice, 7 multiple times and 1 during the entirety of the experience), of the 13 others, 8 were too involved in the gaming tasks to be conscious about their heart rate and 5 just didn't trigger the modifiers and



(a) Subject number 10

(b) Subject number 15

(c) Subject number 26

Figure 1: Plot of three participants heart rate (BPM) over time during the biofeedback experience. The first horizontal line represent the calibrated rest value, the second one the calibrated value plus 15 BPM and the third one the calibrated value plus 30 BPM. (a) Reported never trying to control his/her heart rate. (b) Reported reported trying to control his/her heart rate multiple times. (c) Reported trying to control his/her heart rate once or twice.

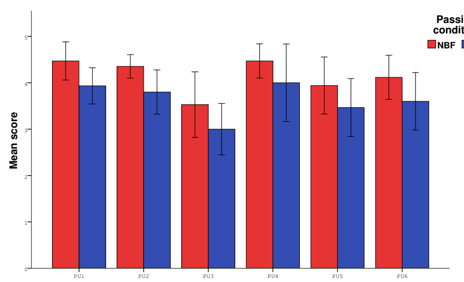


Figure 2: Subjective feedback on the perceived usability of the application divided in two groups non-biofeedback (NBF) and biofeedback (BF).

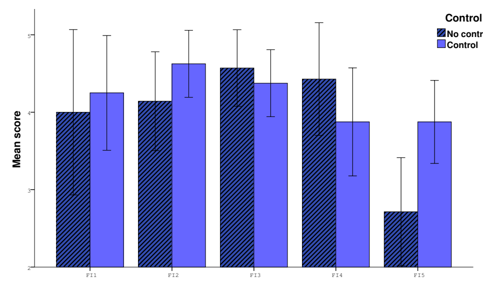


Figure 3: Subjective feedback on felt involvement: BF Uncontrolled heart rate VS. BF Controlled heart rate.

thus didn't need to act accordingly. We compared these answers to the actual heart rate data recordings and we noted that 12 of the 19 participants that reported trying to control their heart rate succeeded in doing so. Figure 1 shows three recordings of heart rate during the biofeedback round, the first graph represents a subject who reported never trying to control his/her heart rate, which continued to rise throughout the experience. The second graph does not show significant drop in heart rate while the subject reported trying to control his/her heart rate multiple times. In comparison subject 26 reported controlling his/her heart rate once or twice and successfully reduced his/her heart rate (once) over an extended period of time.

The results of the Mann-Whitney tests showed significant differences for the questions PU1 ($Z = -2.070$, $p = 0.038$) and PU2 ($Z = -2.280$, $p = 0.023$). The results tend to show a better perceived usability for the non-biofeedback condition (see Figure 2). We note that there is a significant difference between the time of survival of the two groups, the NBF group surviving longer than the BF group (BF Survival time mean=131.27s, NBF Survival time mean=180.59s, $Z = -2.798$, p=0.005). It is understandable, as adding more game mechanics can render the game harder to master, especially physiological data, which are not immediately controlled by the participant. Despite this apparent deterioration, the results are still positive, showing a strong perceived usability. We can highlight a tendency towards a better perceived usability for the NBF group, for questions PU3, PU4, PU5 and PU6, leading to the conclusion that the use of biofeedback adds a complexity to the game. However the results are still high in both conditions. The analysis of the interviews confirms these findings.

Our analysis didn't show any significant differences for the involvement part of our questionnaire. We notice similarly high scores in both conditions. Regarding question FA2 the results show that in both conditions the users didn't pay attention to the outside world (M=4.28, SD=.888), with no significant differences between groups. Participants also reported spending way more time in the game than the actual time, independently of the passing condition (FA1, Mean difference=249s, SD=221s, Max=840s, Min=-71s). This shows how highly focused and engaged were the participants during the experience, regardless of the passing condition.

A finer analysis of the results of the participants in the BF group that tried to influence their heart rate (N=8) and those who didn't (N=7): participants who reported trying to influence their heart rate reported a significantly higher degree of fear than those who didn't try to influence their heart rate (FI5, $Z = -2.508$, p=0.012). While not significant we observe a tendency for higher involvement when the participants actively tried influencing their heart rate (see Figure 3).

16 participants said they preferred the experience using the heart rate, 5 the one without and 11 had no preference. Interestingly we

noted that, of the participants who started in the NBF condition 10 liked more the biofeedback version of the experience and 1 the one without biofeedback. The participants who started in the BF condition had more split answers, while 6 preferred the biofeedback version of the game 4 preferred the one without. Coupled with the interviews, this confirms a learning effect, some participants said they"*knew more what to do the second time and had a better experience*".

When asked if they noticed differences between the two experiences (on a 5 items Likert scale, 1-None, 5-Strong differences) the participants reported diverse answers (M=3.25, SD=1.16). Moreover, considering the analysis of the heart rates recording we can conclude that for 27 participants the biofeedback loop was actively influencing the experience.

5 DISCUSSION

As far as we know, this is one of the first studies to directly explore the effect of a fear biofeedback loop mechanic for immersive VR games. One of the goal of our experiment was to confront the participants to a negative biofeedback loop, encouraging them to try and control their psychophysiological state. By informing them beforehand that their heart rate would influence the experience we wanted them to try and focus on reducing their own heart rate in order to complete the experience. From our results we can partially validate the hypothesis H1, because only some users were capable of controlling their heart rate (12 of the 19 that actively tried). While the number seems low, a lot of the participants didn't try regulating their heart rate, too focused on the experience, similarly to Dekker et al. [8].

Surprisingly we did not observe significant differences in involvement between the two groups. We can't clearly conclude that the introduction of the heart rate biofeedback loop enhances the participants' engagement (hypothesis H3). While the participants reported mostly preferring the biofeedback enhanced experience, like most of the previous studies ([8, 9, 17]), the first results in engagement clash with [16], where the biofeedback is a significant vector of higher engagement on a classic computer game. HMD experiences bring a lot of engagement to their participants, as we were able to report high levels of focused attention in both conditions. This points to a design effect of our experience. Indeed, the biofeedback mechanic is not a mandatory part of the game to avoid any frustration of participants. Thus, the effects in the game may not be visible enough to influence participants' involvement. Indeed, a finer analysis showed that when the participants actively tried to integrate the biofeedback mechanic in their gaming experience showed a tendency to higher involvement. By giving the participants a bigger incentive to control their heart rate and clearer markers of its effects, the game would encourage them to fully take into account the biofeedback mechanic and thus feel more engaged in the experience.

The addition of a new game mechanic can increase the difficulty in mastering a game, biofeedback especially, as controlling one's own heart rate can prove difficult. That is why we hypothesized that adding this physiological loop would enhance the difficulty of mastering the game and general perceived usability. Finding some significant differences between the two groups, in favor of the non-biofeedback version of the game confirmed a steeper learning curve and higher difficulty to master the game with the biofeedback loop. Even if these findings satisfy our hypothesis H3 we did not expect such positive results in the biofeedback condition. Indeed while it render the game harder to master, most of the questions did not return significant differences and scores remained high. Hinting towards the fact that the biofeedback loop might not be too disturbing to the user and not hinder the experience by making it too difficult to tackle. As it was not a mandatory part of the gaming tasks the participants could just ignore the biofeedback and this could justify why it wasn't too detrimental to the overall usability.

6 LIMITATIONS

There is some limitations in our work. First of which is the technical limitations imposed by the Mio LINK. The data provided by the wristband, number of BPM, cannot be used to deeply analyze user's emotions. For the time being, it is only unidimensional, we can detect one emotion we know the experience is designed to induce, may it be joy, fear or boredom. Moreover one participant reported being completely desensitized to horror games, which was in accordance to his/her physiological data recordings. This participant even suggested the opposite of our chosen design: "*if you detect that I'm not reacting, then launch a jump-scare to force the reaction and engage me in the experience*". Similar to some of biofeedback game design proposed by Gilleade et al. [16]. This highlights the limits of the emotions detection system brought by the setup we choose to progress toward game mechanics development.

When designing our experiment we choose to not record engagement data for the second round to avoid any bias. It would be interesting to conduce intensive pre-experiments and tests beforehand in order to measure the habituation effect. Indeed we noted that the participants still felt fear in the second round, despite knowing what would happen. If the habituation is not too high, it would be possible to have the participants answer the questionnaire twice and compare the results, in a *within-group* condition.

7 CONCLUSION

In this paper we have presented a VR game where the more afraid the player is, the harder the game becomes, this concept has already been developed in other games (*Nevermind*[2]), but it was not specific to VR. We hypothesized that it would bring more engagement to the users as they are more wholly immersed into the virtual environment. The results of this experience supported some of our hypotheses.

Our experience demonstrated that despite the novelty of the technology, participants were able to, to a certain degree, control their physiological reaction and experience the game fully. However it is important to note that there is a steeper learning curve with the addition of the biofeedback and thus a more complete tutorial needs to be done when introducing this mechanic to a game. Plus the answers to our questionnaire showed that even the players who were not actively trying to control their heart rate mostly preferred the biofeedback experience, one justified that choice as it "*felt like a story I writing myself rather than a pre-written experience*".

[2]Flying Mollusk - http://nevermindgame.com/ - 2016

We were not able to significantly highlight a difference in user involvement between the participants who realized the experience with biofeedback and those who did without it. However we observed a tendency in higher involvement and some significant differences for the participants who actively tried to influence their heart rate compared to those who didn't. In our experience, biofeedback was not mandatory, the effect might have been not noticeable enough for the participants. The incentive to purposefully integrate the biofeedback mechanic to one's experience is crucial in making the game more engaging to the participants and should be thoroughly considered when designing the game. The balance between the effects on the experience, difficulty in control and rewards is complicated to reach and needs more testing in different conditions.

Discussing with the participants after the experiments some were enthusiastic about these future interaction mechanics in "*entertainment, medical field, emotion recognition and training*", confirming the general interest of the introduction of biofeedback in VR.

8 FUTURE WORK

For the experience presented in this paper, the biofeedback loop is an additional mechanic that the participant can ignore, to a certain degree. Meaning that it is not mandatory to control one's own physiological state in order to complete the game. Contrary to this experience, we would like to make the physiological control mechanic mandatory to complete the game. The goal being to see if it is a possibility or if it is too hard for the user and thus a hindrance to the experience. We plan on investigating the feelings of engagement and agency depending on competency. Firstly we plan on establishing a competency scale for influencing one's own heart rate. Then we could confront the participants to a VR experience where heart rate control is mandatory to complete the game, according to their competency.

The results we obtained are encouraging, as we successfully and reliably integrated a smart wearable in a VR experience involving mobility.

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