Integrability and Reliability of Smart Wearables in Virtual Reality Experiences: A Subjective Review

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ABSTRACT

Virtual Reality (VR) is now an affordable technology that is starting to penetrate the mass market. While cardboard is the most distributed system, it lacks interaction to provide really engaging experiences. Providing low cost solutions to enhance VR experiences is crucial. We hypothesized that the integration of a smart wristband in a VR experience, provide a reliable and comfortable enough setup to add a biofeedback loop to a game. We created a physiologically enhanced game and coupled it with a smart wristband capable of monitoring one's heart rate. We tested our game with and without biofeedback and compared the reported novelty. We observed a high interest of the participants for the integration of smart wearables in VR. We highlighted the stability of our setup, even in mobility and the reported absence of discomfort created by the addition of the wristband.

CCS CONCEPTS

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

KEYWORDS

Virtual Reality; Physiological Sensors.

1 INTRODUCTION AND RELATED WORK

After a dip in the Gartner Hype Cycle for emerging technologies, Virtual Reality (VR) is back in the spotlight. It is now becoming a first class platform in the evolution of creative media.

Each person possessing a smartphone could soon have access to high quality VR experiences. While we can admit that visual immersion provided by a smartphone powered Head-Mounted Display (HMD) is close to the one of traditional HMDs, one of the fundamental and necessary component of a quality VR experience is lacking: interaction. Indeed, traditional HMDs bring controllers (wand and Roomscale tracking for the HTC Vive and Oculus Touch), but mobile platforms don't provide direct and natural interaction schemes. They rely mostly on a visual focus command on an element of the environment, making the interaction artificial and severely limiting user experience.

However, smartphones are anchored in a very large ecosystem which can provide interesting elements to the interaction problem in mobile virtual reality platform. The Internet of Things (IoT), is a flourishing technology, according to Evans [5], it is estimated that by 2020 there will be 50 billions smart objects deployed.

It is important to differentiate the smart objects that enhance the environment [12] from those worn by the user, building *in fine* what is called the *body sensor network*. The concept of *body sensor network* was defined by Ali et al [1] as coming from the concept of "Wireless Personal Area Network" around the 1995s. Its main advantage being that it allows users to move freely while their vitals are monitored by the smart objects (the "network" is moving with them).

The integration of the body sensor network in virtual reality experiences is already possible. It is now crucial to study usability, potential and acceptability of such devices *as is* in VR experiences. In our studies we consider smart wearables that provide two types of data:

- Physiological data, which can provide biofeedback mechanics.
- Data coming from inertial measurement units (present in a majority of smart wearables). They can offer basic motion tracking for direct interaction and navigation metaphors.

In an immersive VR experience it is important not to break the engagement (break in presence) [11]. Thus the goal is to use non-cumbersome sensors that will be integrated naturally to the immersive setup while still providing a physiological monitoring precise enough to be exploited in real time. It is following this logic that the Body Sensor Network is considered a serious option. A recent study conducted by medical doctors and researchers [9] tried to compare the reliability of heart rate data monitored by smart wristbands. Their results show that the data provided by those sensors are precise enough to be used for entertainment and sports. Zuger and Fritz [13] studied the potential usage of wearables in assessing worker's psycho-physiological states in order to predict their interruptibility. Their results demonstrate the potential of these sensors in real-world context, for software developers.

To this day very few studies have been conducted on the combination of VR and IoTs, as demonstrated by the study of the state of the art and potentialities written by Siriborvornratanakul in 2016 [10]. A study of feasibility realized by Muñoz et al. [7] allowed them to develop a framework for mobile VR, facilitating the integration of physiological data from Android wearable sensors (for heart rate), Myo (for electromyography) and Muse (for electroencephalography). They developed a case study for the framework: EmoCat, a game in which the player has to regulate his/her heart rate to find a lost cat in a forest. It is one of the first study on this topic and it offers interesting perspectives for the future of our study.

If numerous studies highlighted the interest of the usage of physiological data for biofeedback loops in VR experiences [2, 4] and entertainment applications [3, 8] very few addressed this problematic with the IoT angle, as they offer great portability and freedom of interaction. While smart wearables still lack precision in their monitoring of physiological data, their usage in the VR spectrum is promising. With the advent of mobile VR, it is important to study the feasibility and the contributions of these new devices (such as smart-watches, activity trackers, etc...) in creating new interaction mechanics and providing biofeedback for affordable virtual reality. In this study we investigate the comfort of use and stability of the wearable sensor in a VR experience involving mobility.

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, and an external application to connect our smart wearable and transmit the data to the game. This section details the setup and applications developed.

2.1 Apparatus

The equipments used for this experiment were a HTC Vive VR system, a desktop PC with an Intel Xeon E5-1603, 8GB RAM and a Nvidia Geforce GTX 1060 graphics card, a Mio LINK heart rate wristband, a headset and a a Bluetooth dongle.

We decided to use the HTC Vive for immersion and interaction, mainly due to the room-scale system that allowed us to create an experience that involves user mobility. 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, stress or relaxation levels, to interpret some basic emotions. During development and with extended research on the Internet we discovered that there was a general construction defect with the Mio LINK, as the broadcast range was really low (about ten centimeters). To deal with this issue we had to incorporate an additional Bluetooth dongle to our setup that was plugged in the Vive HMD USB ports and have it strapped to the participants upper arm.

Figure 1: The full setup.

2.2 VR Game

The goal of the experience is to induce fear to the user, one of the simplest emotion to induce [4]. Lobel et al. [6] 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 (inspiration that can be found in a game like *Bioshock Infinite*[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. To create an engaging experience we added a goal to reach, the participant has to delay the arrival of a creature (represented by a typical horror genre "little girl", see Figure 2) and survive during a five minutes nighttime, equipped only with a flashlight.

2.3 Influence of the physiological data

To estimate the psychophysiological state of a participant we analyze the evolution of physiological data compared to a resting estimate, calculated over a period of 2 minutes and 30 seconds. The effect of biofeedback, monitored by the Mio smart wearable, influenced different elements of the game. With a significant increase in heart rate, compared to the resting estimate came: a diminution of light emitted by the chimney, an acceleration of the frequency of the random elements of the game (door opening and music box playing), a sound of heart beat going faster and louder or a reduction of the user's field of view. If the value of the participant's heart rate goes back close to the calibrated resting 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:

[1]Irrational Games - https://bioshockinfinite.ghoststorygames.com/the-game - 2013

Figure 2: The creature in the middle of the main room.

ID	Question
NO1	How interested did you feel in my gaming task?
NO2	How much did the content of the game incited your curiosity?
WR1	How much did you feel bothered by the wearable during the experience?
WR2	During the experience, how many times did your focus shifted toward the wearable rather than the game?
WR3	During the experience, did the usage of the wearable seemed natural?
CP1	Which of these experience did you prefer?
CP2	How much difference did you feel between the two experiences?

Table 1: Post experiment questionnaire composed of 3 dimensions: Novelty - NO; Wearable - WR; Comparison - CP.

- No biofeedback: the game is not enhanced by the physiological loop.
- Active biofeedback: the game is enhanced by the user heart rate, causing changes in the game's mechanics and environment.

To obtain the participants feedback on the experience we built a questionnaire about the comfort of use of the wearable (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 a series of questions comparing the two experiences. But to avoid any bias due to the importance of the fear effect in our experiment, we decided to register novelty only after the first passing.

3.2 Experimental procedure

First the participants are invited to the experiment room and 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, what types of games they played, sensitivity to motion sickness).

Whichever group they are assigned to, the participant are equipped with the Bluetooth dongle and the Mio wristband. If they are part of the active biofeedback group (BF), we proceed to start the calibration phase. Once the calibration is done, they put on the 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 the voice over and that once they are done listening to it they can ask questions if something is amiss. Once those questions have been answered they proceed to start the experience. The procedure is the same for the non active biofeedback group (NBF) except we don't perform the calibration phase and don't inform them about the usage of heart rate.

Once they complete the first passing, the participants are asked to answer the questionnaire about the novelty of the experience and the presence of the wearable. If they are part of the active biofeedback group (BF) they also answer questions about the usage of biofeedback. This time also allows the participants to get their heart rate back to a resting state.

After the questionnaire they gear up again to redo the experience in the opposite condition (with the calibration phase beforehand if necessary). 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 (17 who started in the non biofeedback condition (NBF) and 15 who started in the active biofeedback condition (BF)). They were 9 women and 23 men, their age ranging from 21 to 44 (M=25.3, SD=5.5). We purposely selected people familiar with VR as to avoid them being more focused on discovering the device than living the experience. 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). 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 presence of the wearable doesn't disturb the user, not provoking any comfort problem within the setup.
- H2: Wearables allow for qualitative enough measures, that can be used in VR experiences.

4 RESULTS

To analyze the results of our experiments we first looked into the reported novelty of the experience. We then qualitatively looked at the reliability of the setup and finally at the reported discomfort of the wearable. For the questionnaire's answers on novelty we performed a non-parametric tests using a Mann-Whitney test, as we used two independent samples for which the Shapiro-Wilk test demonstrated the non normality of the distributions of the answers. These results are described more in detail in the rest of this section.

While our recruited panel is experienced in VR, the novelty of the experience reported by the NBF group was still very high. As a matter of fact on the novelty aspect of the experience, we observed no significant differences between the two groups, despite a slight tendency of higher reported novelty in the BF condition. Both

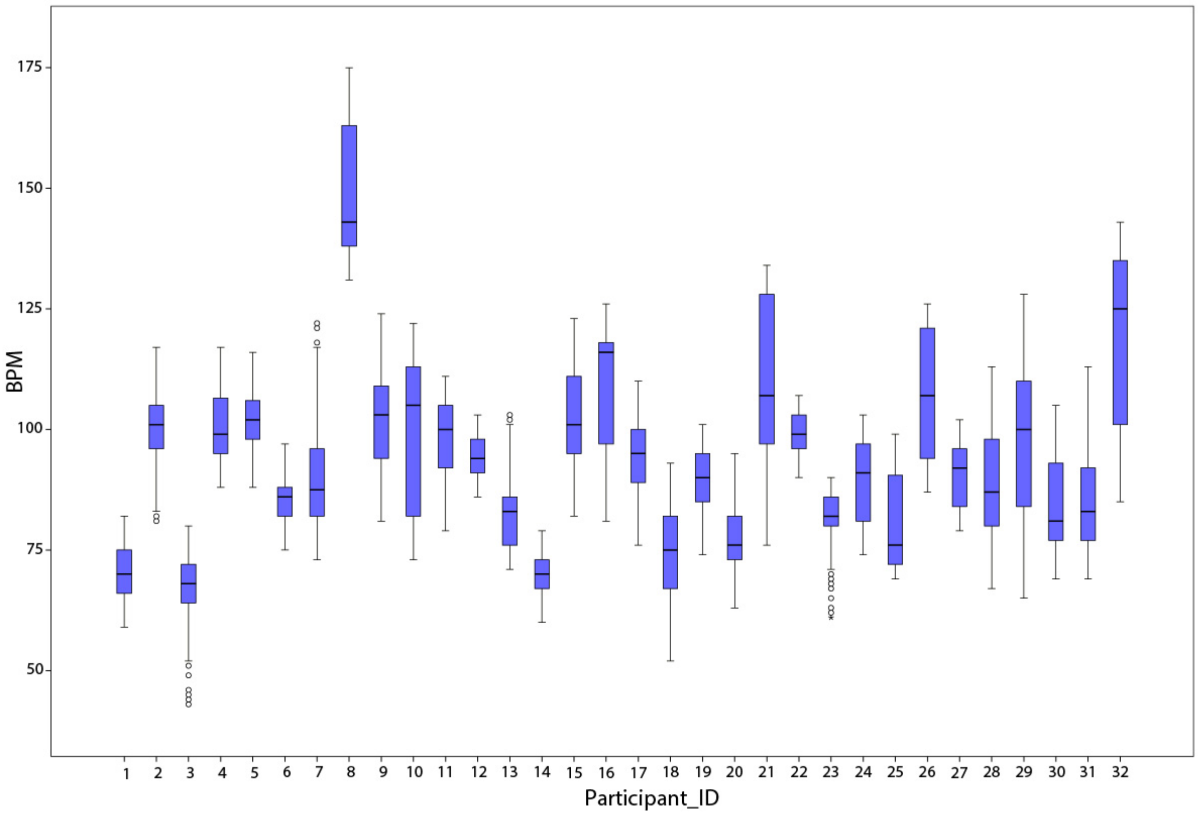

Figure 3: Box plot of each participant's heart rate values recorded during their respective biofeedback passing.

groups reported a high feeling of novelty ("How interested did I feel in my gaming task?", NBF: M=4.06, SD=.899; BF: M=4.20, SD=.857. "How much did the content of the game incited my curiosity?", NBF: M=3.88, SD=.862; BF: M=4.20, SD=.561).

When passing the experiment the participants were equipped with the full setup, whichever the condition, we could then collect information about the comfort of use of the wristband after the first passing. Participants reported that the wristband did not provoke any discomfort during the experience, on a Likert scale from "1-Heavy discomfort" to "5-No discomfort" the mean result was 4.5 (SD=1.19). Only three participants answered 1 and later justified it by pointing the extra cable that was connected to the Bluetooth dongle. 29 participants reported never focusing their attention on the wristband and only three reported focusing on it once or twice during the entire experience (not the same participants as the previously cited). Also on the question "did the usage of the wristband feel natural?"("1-unnatural" to "5-completely natural"), the participants reported a natural usage (M=4.66, SD=.83).

During our experiments we have not recorded a disconnection from the Mio wristband, for the 64 passings we realized. While the quality of the data recording was expected [9], we were not sure how the device would fare against movement. By observing the recordings of the participants heart rate data we were able to determine no aberrant data, we can see in Figure 3 that very few data are considered outliers.

After the participants completed the two passings, we asked them which of the experiences they preferred. 16 responded the one using the heart rate, 5 the one without heart rate 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 reporting that he/she "*knew more what to do the second time and had a better experience*".

During the interviews we asked the participants if they thought the use of physiological data was interesting in the context of VR (not only for gaming) and all of them reported that it was an interesting addition to the technology and almost all of them reported not being bothered by the privacy aspect of the data recording, "as long as [they're] informed beforehand and the data usage is limited to the game".

5 DISCUSSION

As far as we know, this is one of the first study to explore the usability and stability of smart wearables as ways of monitoring physiological data to add biofeedback to VR immersive experiences.

We designed a fear inducing experience for this experiment. Overall our data allowed us to validate our hypotheses. However we were not able to find significant differences in the novelty factor between the two passing conditions.

When we designed this experience we expected the wearable to integrate itself naturally in the setup, the participants not feeling bothered by the wristband. The data returned by the participants validated our hypothesis H1, the wristband integrating itself naturally into the VR setup and being almost unnoticeable by the participants. Moreover, the analysis of the heart rate monitoring data during our 32 passings confirmed the reliability of the smart wristband device in a VR experience involving movements, as we didn't suffer any disconnection and we observed very few outliers data during the experiments. These results are also in accordance with previous findings [7, 9, 13] on the reliability and usability of heart rate wearables.

The fact that the novelty factor was not significantly different between the BF and NBF groups, even if a small tendency is showing a stronger reported novelty for the BF condition, tends to show the still high impact of VR on the user. Indeed while our participants were experienced users of VR they reported high values of novelty in both conditions.

Interestingly our participants feedback pointed toward a great interest in combining both technologies and possibly using it in the future, whether it is for entertainment, training or even medical purposes.

6 LIMITATIONS

There is some limitations in our work. First of which is the technical limitations imposed by the Mio LINK. The range problem of this specific device forced us to add more cables to the set up, which some participants reported "bothered [them] during the experience".

We also couldn't equip the participants with additional sensors that could help us identify the sensor's errors, however the added gear would change our analysis of comfort and cumbersomeness. The second point we can mention is the relative reported lack of novelty provided by the wearable, which is hindered by the still novel medium that is virtual reality. This tends to trigger less interest in the biofeedback than expected, as participants are still more focused on the VR part of the experience and not necessarily noticing the addition of physiology. This can also be linked to the general design of the game and the too tame effects of the biofeedback loop on the game.

When designing our experiment we choose to record heart rate data for both passings, biofeedback and non-biofeedback to test the robustness of our system. However it would have been interesting to have the participants strapped only during the biofeedback passing to compare how the overall comfort changed between the two conditions.

7 CONCLUSION AND FUTURE WORK

7.1 Main findings

The primary focus of our work was to demonstrate the reliability and usability of wearables as tools to add biofeedback to virtual reality experiences. For this we developed a fear inducing VR game and coupled it with a smart wristband capable of monitoring heart beats per minutes. We were able to confirm to some extent the reliability and usability of the body sensor network in the case of VR experiences and noted interesting results to further our research on the subject.

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 and didn't focus on smart wearables as physiological monitoring tools. The results of this experience supported that the utilization of smart wearables was a possible alternative to medical devices as a way to bring physiological monitoring to the user in VR setups for entertainment and training. And while it lacked the precision to provide in depth emotion analysis, the quality of the recordings, comfort of use and reliability of the device qualified it as a solution for biofeedback in VR experiences, even the ones involving mobility.

Our experience also demonstrated that despite the novelty of the technology, participants were interested in the experience and the combination of both medium.

Discussing with the participants after the experiments also confirmed the general interest of the users in the introduction of biofeedback in VR and its future use in entertainment, medical field, emotion recognition and training.

7.2 Future work

We are interested in testing our hypotheses with other devices monitoring different types of physiological data, such as the electro dermal activity (EDA) to evaluate differently emotional cues.

We plan on deploying our solution on more experiences to put our setup to the test, proving our hypothesis even more. The next step is to have the solution integrated in a mobile setup to test how effective it is to help bring interaction to low cost VR experiences.

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