Heart Rate Sonification in a Biofeedback Shoot 'Em Up Game

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ABSTRACT
Biofeedback is a method of improving one's ability to control body functions. The following paper intends to develop insight into how auditory feedback of heart rate in an affective game affects the player's ability to control it. In order to research the matter, a bespoke game has been developed where the player, connected to the set of sensors, controls the game's difficulty by adjusting their heart rate.

We gathered data from a series of experiments. First, we recorded participants' in-game performance for both affective and control versions of the game. Unfortunately, the results did not differ between the two groups. However, the paper intends to explain encountered problems and drawbacks of the applied method and include recommendations on how we could improve future studies.

Keywords
Games, Playing, Heart-rate biofeedback, Design, Performance

INTRODUCTION
The utmost essential elements of every video game consist of communication with the player. The player provides an input to which the game provides feedback, usually visual or auditory. Usually, player-game communication ends here, yet it is not where player messages end.

The human body continues to respond to the communicated messages with breathing, heart rate, muscle contraction, sweat gland activity, and body temperature. Bodily functions provide information about the player's state, similarly to a set of screens and speakers providing the player information about the state of the game. Unfortunately, most non-serious games do neither record any of this data nor actively respond to it. The following paper will explore the incorporation of biofeedback in effective gaming, i.e. "new generation of games in which the players' behaviour directly affects the game objectives and gameplay." (Kotsia, Zafeiriou & Fotopoulos, 2013).

Biofeedback, a technique of improving an ability to control these body responses, focuses on connecting a person to a set of sensors under an assumption that with feedback, said person will find it easier to make subtle adjustments, e.g. heart rate. "In essence, biofeedback gives you the ability to practice new ways to control your body, often to improve a health condition or physical performance" ("Biofeedback - Mayo Clinic", 2022).

RELATED WORK

Affective gaming may be instrumented physiologically using biofeedback - a technology that stimulates the user to become aware of their own physiological processes that occur within the body, which usually occur imperceptibly to our own perception. Through the effective usage of applied biofeedback, awareness of such information can be used to treat medical conditions by allowing users to exert conscious control over their mental processes (Gilleade et al., 2005).

Video games have been used previously in contexts of affective awareness training or treatments, but not always successfully. A physiological receptive game must be able to transmit effective feedback in order to become effective. For such tools to become successful, designers must make sure that the computer is an active participant in the feedback loop. Hence, both the player and game should consistently be affected by one another (Gilleade et al., 2005).

One significant contribution to this ever-growing field of affective gaming would have to be Sonic Cradle, a title that reproduces the experience of practising mindfulness through a more accessible approach. Sonic Cradle is a potent example of an interactive system that provides the user with the moment of stillness and self-reflection that other mindfulness training makes use of to promote well-being (Vidyarthi & Riecke, 2014).

Our research drew inspiration from Ilkka Kosunen et al. (2018) work, EmoPoker, which uses biofeedback to train and stimulate skill improvement at poker. Their hypothesis is based on the fact that poker play is rigorously linked with emotional stimulation. As a result, EmoPoker is an effective self-training tool that provides easy-to-use recognition and comprehension of a player’s mental state.

RESEARCH QUESTION

Does hearing a sonification of one’s heart rate stimulate improvement of their ability to control their heart rate in a heart rate variability (HRV) impacted biofeedback video game?

METHOD & MATERIALS

We conducted an experiment with two conditions: a treatment group heard their actual heartbeat and a control group heard a constant heartbeat. First, to rule out the possibility that simply listening to a heartbeat would produce the desired effect.

Participants

A pilot study with 11 participants was conducted to test the experiment's setup. These results are excluded from the analysis. For the final test, 26 participants were recruited, including friends, families, and roommates of the researchers and students from Leiden University. They were randomly assigned to one of the conditions.

After the pilot study, it became clear that game variables affecting difficulty required tweaking. For example, enemy movement speed was lowered, player health points were doubled, and enemies took one hit to be killed.

Game
The main inspiration for our self-developed game was an old Shoot'em up PlayStation title called Resogun. Our motivation for choosing such a fast-paced type of experience was based on account of its effectiveness in prompting intense affective stimulation for longer intervals of time, with breaks in between the wave spawning.

Biofeedback Implementation
The bio-feedback implementation was set up in such a way that it functions as an active agent within the affective feedback loop. Accordingly, we decided that the biofeedback data consistently received should not only influence the game itself but act as the main mechanic of the game simultaneously.

A visual and sonification version of the participant's heartbeat would be made accessible for the player. In addition, three separate thresholds were set up so that, if the BPM exceeded them, the game's difficulty would automatically be increased as well, and conversely in the case of the BPM going down. Consequently, the already fast-paced game experience would progressively be influenced in real-time by intensifying the speed of the enemy agents that were spawned through waves.

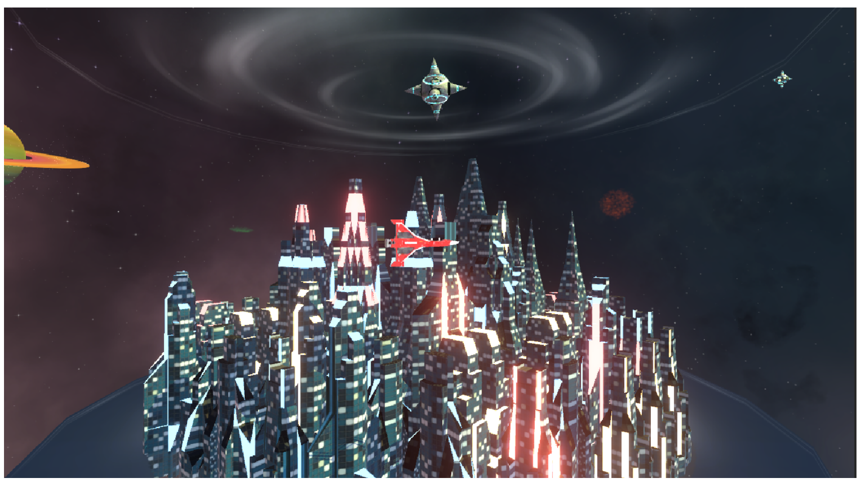

Figure 1: Screenshot of the game: *Invaders*

Hardware
As part of the hardware, we used a simple pulse sensor that can be clamped on the fingertip. The sensor was part of the Shimmer Research package; however, the data could only be used when we activated an expensive paid license. Therefore the sensor was attached to an Arduino. With this self-built setup, the threshold for each participant had to be adjusted manually. When set, the sensor data could be sent to Unity over the serial. Adjusting the parameters for every participant was time-consuming, but luckily, it worked. Unfortunately, a script or algorithm for automatic heartbeat peak detection was not available; therefore, we decided to do this manually.

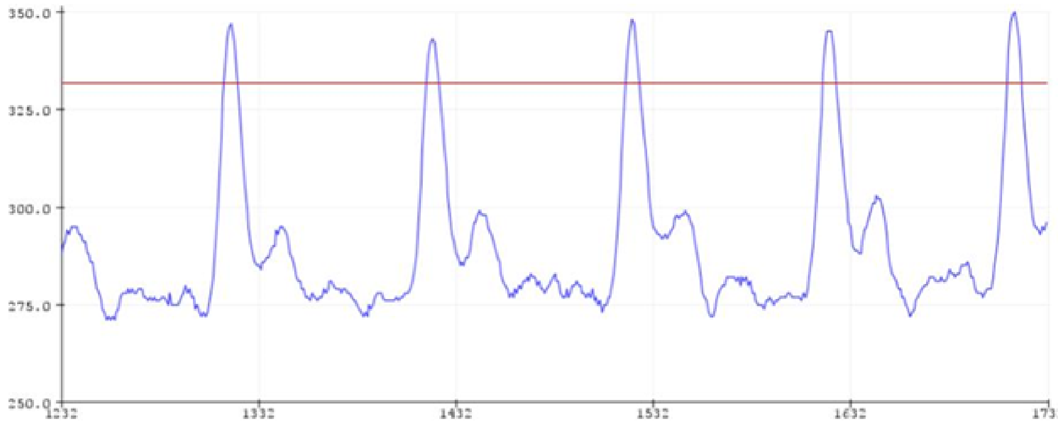

Figure 2: Redline is the threshold of heartbeat peaks

Once the threshold was correctly set, the code calculated the heartbeats per minute and sent this over serial to Unity. Every heartbeat was the trigger to transmit this data, so if Unity received '67', that meant that 67 heartbeats happened at the peak in the last minute.

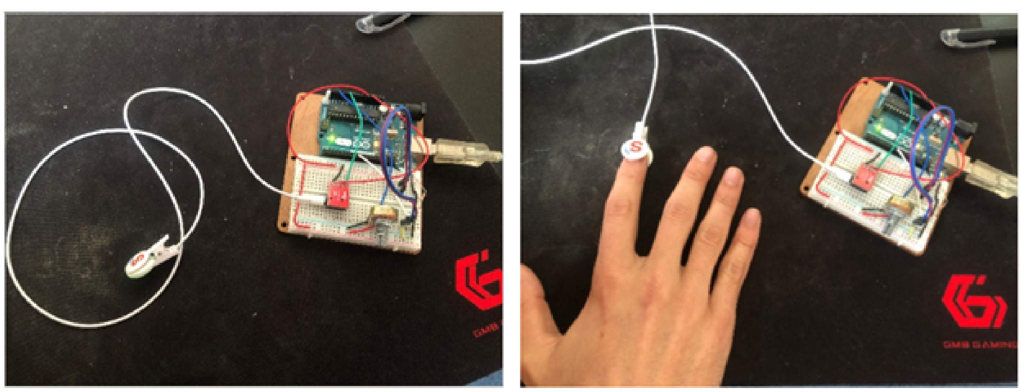

Figure 3: Arduino setup with pulse sensor placed on the index finger.

Measurements

At each heart rate measurement, we recorded the following data: participant identifier, beats per minute (BPM), control group (boolean), seconds elapsed (2 decimal places), wave, score and DateTime.

Procedures

The experiment was conducted by three researchers in a classroom at Leiden University and at two of their homes. We followed no strict protocol, but we established general guidelines for the participant's guidance and information.

Participants were told that their heart rate was being measured and that this affected the game's difficulty. They did not know if they would hear a (real/fake) sonified heartbeat. The goal of the game was to stay alive as long as possible. It starts off simple but becomes more complex as you progress. When an enemy collides with the ship, you take damage, displayed in the health bar on the bottom right. The health slowly regenerates over time.

After the debriefing, the sensor was clipped on the participant's index finger. We ensured that all participants were seated comfortably in a fixed position, which was necessary for a reliable measurement. The researcher put on a pair of headphones, and we made sure that the heartbeat was clearly audible; however, volumes could vary.

Once the equipment was set up, participants could familiarise themselves with the game by playing the first one or two waves. We stopped the game when we felt that the participants understood the gameplay. Data was not captured yet in this phase. After that, the actual experiment could start. Participants played until they ran out of lives.

RESULTS

Two experiments were done, a pilot study (n = 11) and the final experiment (n = 26). In the pilot study, the average time played was 95 seconds, which we consider to be too short to get a useful result. Therefore only the results of the final experiment will be presented. There were about 40 participants for the final experiment, but the heartbeat sensor did not work on many of them, which is why their data was tossed out. The remaining 26 have successfully completed the experiment, and their data is presented here.

Most results are shown up to 5 minutes of playtime as they give a more realistic view of the differences in performance within the experiment. Participants played our game for an average of 232 seconds (nearly 4 minutes). Few played substantially longer than average, including one who managed to play for almost 18 minutes.

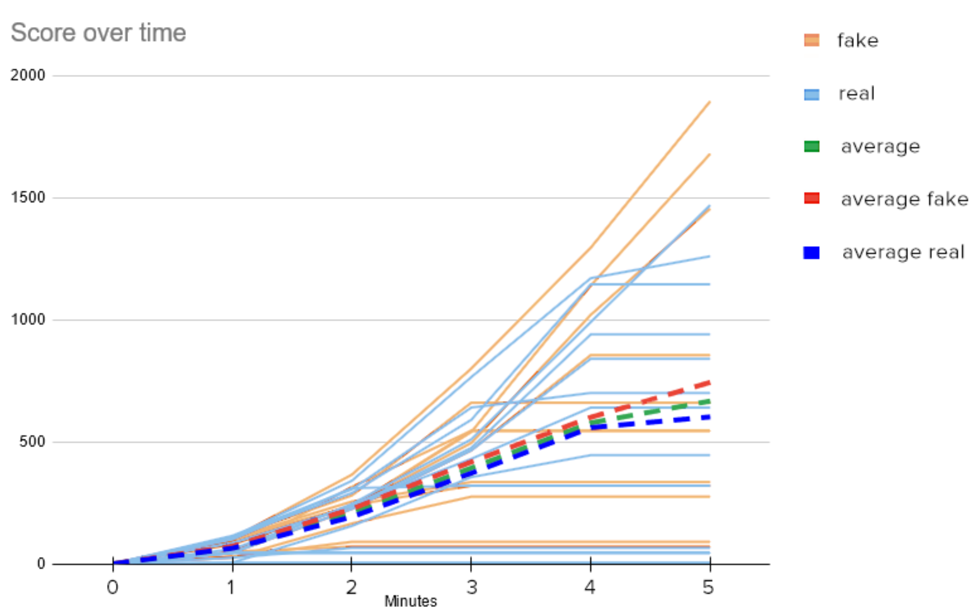

Figure 4: Score over time

In figure 4, we see the score of the players as it develops over time. The score can only increase in the game, not decrease. If a player dies, their score remains included in this graph, but it stagnates at their final score. Orange lines are individual participants who heard a fake heartbeat; blue lines are individual participants who listened to their real heartbeat. The green, red, and blue dashed lines show the average of the fake heartbeat group and an average of the real heartbeat group. We have not noticed a significant difference between the performance of the two groups.

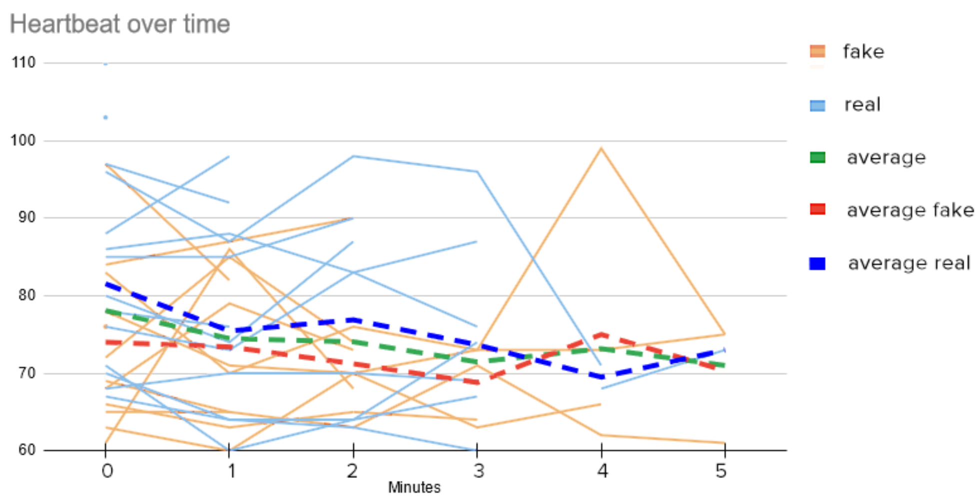

Figure 5: Heart rate over time

In figure 5, we see the heart rate over time, measured in beats per minute. Unlike in the previous graph, when a participant is game over, their heart rate is no longer shown. This explains why some lines stop before they reach the 5-minute mark, some participants are even only represented with a single dot as we could only record their heartbeat at the start; they never made it to the 1-minute mark. The graph suggests that players with a lower heart rate may be more likely to get further in the game. Still, no strong correlation was found with correlation analysis (figure 6).

Pearson's Correlations

Variable		Total time played	Total score
1. Total time played	Pearson's r	—	
	p-value	—	
2. Total score	Pearson's r	0.988***	—
	p-value	< .001	—
3. bpm after 0 min	Pearson's r	−0.156	−0.052
	p-value	0.448	0.799
4. bpm after 1 min	Pearson's r	−0.331	−0.261
	p-value	0.123	0.228
5. bpm after 2 min	Pearson's r	−0.003	0.029
	p-value	0.991	0.905
6. bpm after 3 min	Pearson's r	0.016	0.036
	p-value	0.960	0.912
7. bpm after 4 min	Pearson's r	0.139	0.141
	p-value	0.793	0.790
8. bpm after 5 min	Pearson's r	0.424	0.451
	p-value	0.576	0.549

* p < .05, ** p < .01, *** p < .001

Figure 6: Correlation analysis using the Pearson correlation coefficient

In figure 7, we can see an overview of all the data, split by the two testing conditions. The bpm after 0 minutes is the starting heart rate. Notice that although the mean score is very different between the fake and real heartbeat groups (1491 vs 666), their median scores are very similar. This appears to be because of a single outlier who increased the average score a lot; see the maximum scoring values for the fake and the real groups (8480 vs 2835). Our motivation is also to show the score and bpm at 3 minutes because this is the median time played among all participants.

	avg bpm		Total score		Total time played		bpm after 0 min		bpm after 3 min		Score after 3 min	
	Fake	Real	Fake	Real	Fake	Real	Fake	Real	Fake	Real	Fake	Real
Valid	12	14	12	14	12	14	12	14	5	7	12	14
Missing	0	0	0	0	0	0	0	0	7	7	0	0
Mean	73	83	1491	666	283	175	74	84	69	76	428	340
Median	71	81	545	543	175	196	71	83	71	74	480	393
Std. Deviation	10	16	2407	760	279	112	11	14	5	12	218	256
Minimum	64	65	70	5	79	43	61	67	63	60	70	5
Maximum	92	122	8480	2835	1067	452	97	110	73	96	800	765

Figure 7: Data overview split by real heartbeat and fake heartbeat groups.

DISCUSSION / CONCLUSION

We found no statistically significant results. However, below is an explanation of the problems that may have caused this.

Sensor

The sensor was not always reliable, which reduced the number of participants by approximately half. Furthermore, the participant had to stay still during the experiment; if the user moved his hand slightly, data could be lost. In addition, the sensor was deceptive to light from outside, meaning that direct sunlight could disturb the signal. However, it was also found that shining a (smartphone) light on the sensor helped when the readings did not appear on the serial monitor. Other sensors like the ear clip pulse sensor or an ECG (skin conducting) were considered. After some initial tests, the pulse sensor for the finger worked the best for our setup. Furthermore, the Arduino code for the sensor worked well enough, but some participants were somewhat difficult to measure. If, for example, the sensor's input was too noisy, peaks could not be detected and therefore were not used for the experiment.

Player experience

Higher skilled players will probably be more relaxed, amplifying their ease of playing the game. However, we tried to take this into account by letting the participant play for one minute before the actual test was conducted, which allowed the participant to get used to the controls and feel the game already.

Varying heart rates

We have observed significant differences in average heart rates, ranging from 64 to 122 BPM. Unfortunately, the game does not consider these differences, making the game a lot harder for players with higher heart rates. This should have been accounted for; however, we did not. The other thing is that we did not anticipate participants having a heartbeat above 90 before starting the experiment. Again, this should have been researched beforehand but did not come on our path when designing the experiment.

Test environment

There were differences across the test environments, which may have affected the results. For example, various screens with their own dimensions, refresh rates and response times. Different headphones may display frequencies differently due to equalisation. On some machines, the game runs smoother due to superior hardware.

Instructions protocol

Each participant received instructions before the experiment, and there was a checklist to make sure all important information was mentioned. However, these briefings were quite informal, and the different phrasing of the information or the different questions that participants asked could have influenced how they played the game. A stricter script could possibly have improved this variability.

FUTURE WORK AND RECOMMENDATIONS

First of all, it would be better if the setup was conducted at the same place throughout the experiment. This would ensure identical sound volume, display and keyboard input across all participants. Furthermore, we suggest that future studies use the resting heart rate as the starting point from which the difficulty increases. After that, the code will take an average heart rate a minute before starting the game.

Also, when considering using a particular sensor for your research, conduct some initial tests with actual participants. For example, the sensor worked perfectly within our research team, but it became clear that it was sensitive but accurate when testing with outsiders. Nevertheless, we can not avoid losing some data due to problems with the hardware.

Furthermore, there are probably more reliable sensors such as the Shimmer package and electrocardiogram modules for detecting a heartbeat. However, the shimmer sensor package is expensive, and the ECG electrodes had to be placed on the chest with stickers, which was arguably not ideal for our setup.

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