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Auditory Feedback of False Heart Rate for Video Game Experience Improvement

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Abstract—Changes in emotions affect our physiological responses, and perhaps vice versa. We investigate a new game interaction system that uses false heart rate (fHR) feedback to improve the player experience (PX). The fHR feedback presents false HR information to players so that they perceive changes in the presented HR as being a result of alteration in PX. We introduced auditory fHR feedback into game interaction and investigated its effects through an experiment. Participants repeated gameplay of an action game while hearing heartbeat-like sounds and answered questionnaires regarding PX. Some participants heard the heartbeat-like sounds synchronized with their actual HR, whereas others heard the heartbeat-like sounds whose tempo became gradually faster or slower than their actual HR. The results indicated that an accelerating fHR feedback pattern with +5 bpm/min was appropriate for improving PX; participants were able to maintain their motivation to continue the game. The experiment also indicated that it is necessary for participants to perceive the presented heartbeat-like sounds as reflecting their actual HR. Participants did not maintain their motivation when they were told that the presented sounds were not correlated with their actual HR. The present work provides new principles for video game interaction design based on physiological measurements.

Index Terms—False heart rate feedback, video game experience, physiological measurement, interaction design

1 Introduction

It is well known that changes in our physiological responses are associated with our emotions. The use of physiological measurements in video game design for manipulating player experience (PX) has attracted attention in the game research community. Nogueira *et al.* developed a horror game that uses the player's physiological signals for estimating his/her emotional state [1]. The game system evaluates arousal/valence ratings by utilizing the user's heart rate (HR), facial electromyogram (EMG), and skin conductance. In addition, character status and events in the game change dynamically, which are reflected in the estimated arousal/valence ratings. Parnandi *et al.* also developed a car racing game that utilizes players' physiological signals [2]. The difficulty of the game changes dynamically based on the player's arousal which was estimated from skin conductance.

Although these games assume that the player's emotional states can be estimated from their physiological signals, such emotional state estimation is not always easy due to large individual variability in physiological responses. People may have different feelings even if they experience the same event, and their physiological responses thereto also differ [3], [4], [5].

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The present work does not attempt to estimate the player's emotion from physiological signals but rather focuses on PX manipulation through stimulus by means of false physiological information. False physiological responses are presented to players so that they perceive changes in their physiological responses as being the result of changes in emotions or experiences.

We hypothesize that presenting a higher (false) heart rate than the actual HR to players may create an illusion that they are excited, even if the game is dull. This idea is based on the assumption that stimuli of physiological responses affect emotions because our emotions and physiological responses are connected with each other [6], [7].

The present work aims to design a new game interaction system based on false HR (fHR) feedback for improving the PX of video games. For the purpose of realizing such an interaction system, this work introduces auditory feedback of fHR into a video game and compares different types of fHR feedback patterns through an experiment. In the experiment, participants played a simple action game while hearing heartbeat-like sounds. Some participants heard heartbeat-like sounds that were synchronized with their actual HR measured with an electrocardiogram (ECG) sensor, whereas others heard sounds whose tempo became gradually faster or slower than their actual HR. Changes in the PX were evaluated using the Game Experience Questionnaire (GEQ) which is the most popular questionnaire for measuring playability and attractiveness of games [8], [9].

The remainder of this article is organized as follows. Section 2 presents a hypothesis of an fHR feedback-based game interaction system. A procedure of an experiment for evaluating the effect of fHR feedback is described in Section 3. Sections 4 and 5 report and discuss experimental results. Finally, the conclusion and future works are stated in Section 6. Although a preliminary version of this work has been submitted in [10], the tested fHR feedback patterns in the experiment of this work are different from [10], and the experiment was performed again for this work.

2 Hypothesis

Researchers have long discussed the mechanism of emotions [11]. The James-Lange theory is one of the earliest theories of emotion, which hypothesizes that the origin of emotions is physiological arousal. We experience emotion when the brain reacts to information about the physiological responses received from the body's nervous systems [12]. On the other hand, the Cannon-Bard theory insists that physiological changes in response to a stimulus and emotions are separate and independent, and that physiological responses are not needed before feeling emotion. According to the Cannon-Bard theory, emotion results from the function of the thalamic region, and physiological response recognition results from stimulations of the dorsal thalamus [11].

The two-factor theory suggests that emotion results from two factors: physiological responses and cognitive labels. When we feel some emotion, physiological responses occur, and we search for emotional cues to label the physiological responses that have occurred [6]. If the brain does not understand why such an emotion occurred, it uses external stimulations as cues to label the emotion. This mechanism may lead to misinterpretation of emotion depending on the physiological state, because various stimuli cause similar physiological responses such as increased blood pressure or perspiration. According to Dutton and Aron's experiment, when a person experiences physiological responses related to fear such as increased heart rate or increased blood pressure when crossing a suspension bridge, he/she may mislabel such responses as romantic feeling [13].

In addition, Scherer proposed the component process model of emotions, which advocates that emotion results from the combination of various cognitive and physiological responses [14], [15]. For example, a person labels the combination of eyes widening and heart rate increasing as fear when he/she encounter a snake.

These theories suggest that emotions can be intentionally altered when a person is given a false physiological response. Valins reported that auditory feedback of false HR affects subjective experience [16]. Experimental participants were provided with auditory feedback of fHR while viewing pictures of persons of the opposite sex. They were not instructed that the presented HR was false; the tempo of the heartbeat-like sounds was intentionally altered so that the presented HR was steadily accelerated or decelerated from the reference HR, which was determined from each participant's HR measured during a resting state. The participants in the accelerating group tended to evaluate the pictures of opposite-sex persons to be more attractive than those in the decelerating group. Nishimura *et al.* retested Valins' experiment using tactile feedback generated by a voice-coil type actuator attached to the participant's chest [17]. The self-reported attractiveness scores of the pictures were significantly higher when the participants were given accelerating fHR feedback, compared to those given decelerating fHR or the reference HR feedback.

Some studies have investigated the effect of fHR feedback on experiences other than opposite-sex attractiveness.

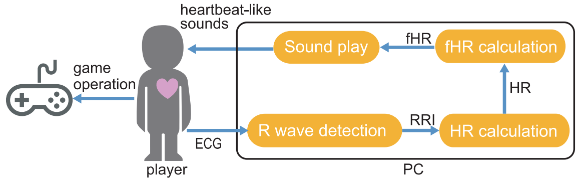

Fig. 1. Schematic diagram of fHR feedback system.

Valins and Ray found that fHR feedback alters fear reactions to the appearance of snakes [18]. Gray *et al.* reported that fHR also affects facial expression evaluation [19]. Ueoka *et al.* developed a tactile fHR feedback device that intensifies the fear of an audience that is viewing a horror movie [20]. Thus, it is expected that fHR feedback can be utilized in various situations, including gameplay.

Based on these theories and findings of the relationship between emotion and physiological response, we hypothesize that the PX of gameplay can be manipulated with auditory feedback of fHR. In particular, we expect that accelerating fHR improves PX. Our hypothesis of PX improvement with fHR feedback is validated through experiments.

3 Experiment

This section describes an experiment for evaluating the effects of fHR feedback on PX. The experiment was approved by the Research Ethics Committee of the Graduate School of Informatics at Kyoto University.

3.1 Participants

Forty-three Japanese individuals (27 male and 16 female) participated in this study. Participants (players) ranged in age from 18 to 27 years (M=21.2, SD=2.17). Since participants were recruited at Kyoto University, all participants were its undergraduate or graduate students. All participants were healthy, with no history of cardiovascular disease and had normal or corrected vision and hearing functions. In addition, we asked participants about play frequency of video games in daily living on a four-point scale: '1: almost every day', '2: several times per week', '3: several times per month', and '4: almost never'. The average scale of gameplay frequency was 2.7, indicating that most participants had enough video game experience.

The total number of participants used for analysis was forty because data collected from three participants could not be used due to measurement failure.

3.2 fHR Feedback-Based Interaction System

Fig. 1 shows a schematic diagram of the fHR feedback-based interaction system used in this experiment. During gameplay, a participant hears heartbeat-like sounds whose tempo is intentionally manipulated based on the HR measured with an ECG sensor.

The ECG sensor used in this experiment was developed by Yamakawa *et al.* [21]. The recorded ECG signals were digitized with an analog-digital converter (cDAQ-9171, National Instruments) at 250 Hz and sent to a personal computer (PC). An R wave is detected by using a first derivative-based peak detection algorithm, and each RR interval (RRI) was calculated. The HR is calculated as $60/\bar{r}_{10}$, where $\bar{r}_{10}$ is the ten-second moving average of RRIs. In addition, fHR is determined based on the

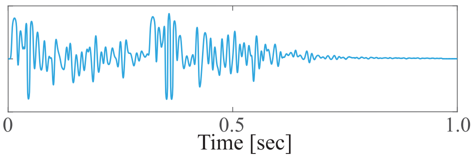

Fig. 2. Waveform of heartbeat-like sound.

calculated HR. The fHR calculation rule is described in Section 3.5. The PC plays the next heartbeat-like sound after 60/fHR seconds from the previous sound play.

Fig. 2 visualizes a waveform of the heartbeat-like sound used in this system, which was created using a free audio editor 'Audacity' [22] to resemble the first and second sounds of a heartbeat.

3.3 Procedure

Fig. 3 shows the experiment protocol. Each participant came to our laboratory twice on different days and played a simple video game under two different conditions: an fHR feedback condition (FB) and a control condition (CTL).

On the first day, all participants provided informed consent after a brief explanation of the experiment. They practiced playing the game briefly after they were equipped with an ECG sensor for measuring HR. Then, each participant repeated the following session five times: 1 minute of rest, 3 minutes of gameplay under one of the two conditions described above, and answering a post-game questionnaire. Participants playing under FB heard a heartbeat-like sound in addition to the background music of the game using headphones. They then answered a post-FB questionnaire after all FB sessions ended. Participants under CTL were equipped with the ECG sensor for measuring HR, and played the game without the heartbeat-like sound, although they wore headphones and heard the background music. The sound volume was kept constant for all participants.

More than one week after the first day, another experiment was performed. Each participant repeated the same procedure as the first day, but under the other condition. Although the order of the experimental conditions assigned to each participant was determined randomly, the number of participants assigned to the two condition orders was made the same to control for order effect.

3.4 Video Game

Fig. 4 shows a screenshot of the video game used in this experiment. The game was developed in Unity, in which participants are required to operate a cartoon character to

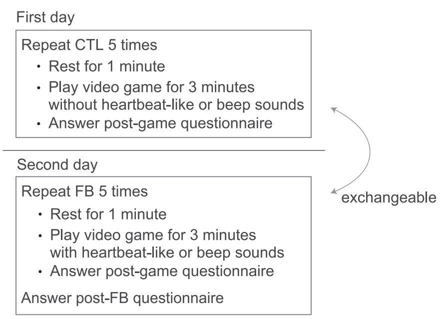

Fig. 3. Experiment protocol.

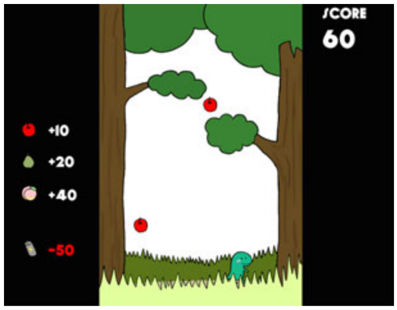

Fig. 4. Screenshot of video game.

catch as many falling fruits as possible. Participants need to avoid falling obstacles, such as batteries. While participants receive points when the character catches a fruit, they lose points when the character hits an obstacle. The number of falling fruits and obstacles in this game is constant. The moving speed of the character and the falling speed of fruits and obstacles become gradually faster to confuse the participants, and the speed is reset at the beginning of each game session. The action required to operate the character was limited to pressing the space bar to turn the direction of the character's movement to minimize motion artifacts in the HR measurement. Additionally, the participants heard monotonous rhythmic sounds as background music from a pair of headphones.

3.5 False Heart Rate Feedback

Under FB, participants heard the heartbeat-like sound in addition to the background music during gameplay. The tempo of the sounds was intentionally changed according to the actual HR measured with the ECG sensor. This intentionally manipulated HR is called false heart rate (fHR). Ueoka *et al.* tested two patterns of HR acceleration for false feedback, i.e., acceleration based on measured HR and linear acceleration regardless of the measured HR, and they reported that the former pattern was more effective than the latter pattern [20]. Thus, the measured HR-based fHR pattern was adopted in this experiment.

Table 1 describes the fHR rules used in this experiment, where t [sec] is the elapsed time from the start of the game. Three groups of fHR feedback patterns were tested: A, slowly accelerating (+5 bpm/min); B, rapidly accelerating (+10 bpm/min); and D, slowly decelerating (−5 bpm/min). For example, the fHR of group A was equal to the HR when the game session started, which became faster and reached 15 bpm faster than the actual HR by the time the game session ended. The pattern for group C was actual HR feedback; that is, the presented heartbeat-like sounds were synchronized with the actual HR. It was explained to all participants that the presented sounds are synchronized with their actual HR, following Valins' experiment [16].

Valins reported that accelerating fHR feedback was more effective than decelerating fHR feedback [16], and our purpose is to improve PX with fHR feedback. Thus, we investigated the tempo of the accelerating feedback patterns (groups A and B), and did not consider a rapid decelerating feedback pattern.

TABLE 1
fHR Feedback Patterns

Group	Pattern	fHR	Male	Female	Frequency
A	slowly accelerating (+5 bpm/min)	$t/12 + HR$	6	4	2.6 ± 1.3
B	rapidly accelerating (+10 bpm/min)	$t/6 + HR$	6	4	2.8 ± 1.3
C	synchronized actual HR (± 0 bpm/min)	HR	6	4	2.9 ± 1.4
D	slowly decelerating (−5 bpm/min)	$-t/12 + HR$	6	4	2.5 ± 1.4

In this experiment, forty participants were divided into the four groups described above. The sample size in this experiment was determined based on 'the 10±2 rule', which is a general rule for sample size for the usability evaluation of human-computer interaction [23]. This rule recommends that the number of participants in each group to be 10±2. In addition, participants were assigned to four groups so that their age, gender, and gameplay frequency in each group were well-balanced.

3.6 Experimental Design

A three-factor mixed design was adopted for investigating the effect of different fHR feedback patterns on PX. The first factor was groups as a between-subjects factor; each group had its HR feedback pattern shown in Table 1. The second and third factors were sessions and conditions as within-subjects factors, respectively.

3.6.1 Group

The between-subjects factor with four levels: A, B, C, and D. The subjective PX ratings were compared between groups A, B, C, and D for investigating the differences in HR feedback patterns.

3.6.2 Session

The within-subjects factor: the repeated time of gameplay. In this experiment, participants repeated gameplay five times to observe how PX changed as sessions were repeated. The subjective PX ratings and the participant's actual HR were recorded during each gameplay.

3.6.3 Condition

The within-subjects factor: FB and CTL. Every participant performed both FB and CTL to evaluate the effect of the existence of the heartbeat-like or beep sounds.

3.7 Measurements

The measured HR and the game scores of a participant were recorded during every gameplay. At the end of each game session, participants were required to complete a post-game questionnaire for evaluating PX. In addition, participants answered a post-FB questionnaire after all FB sessions ended, from which were collected their perceptions of the stimulated sounds.

3.7.1 Post-Game Questionnaire

PX was measured by means of the core module of the Game Experience Questionnaire [8], which evaluates game experiences from the viewpoint of the following seven components: Positive Affect, Negative Affect, Flow, Immersion, Tension/Annoyance, Challenge, and Competence. Table 2 shows the GEQ. All of the items are rated on a five-point Likert scale: '1: Strongly disagree', '2:disagree', '3:Neither agree nor disagree', '4: agree', and '5: Strongly agree'. Each component is evaluated by means of a combination of multiple items; for example, the Positive Affect is evaluated by combining items No. 1, 4, 6, 14, and 20.

TABLE 2
Post-Game Questionnaire

No.	Item	Component
1	I felt content	Positive Affect
2	I felt skillful	Competence
3	I was interested in the game's story	Immersion
4	I thought it was fun	Positive Affect
5	I was fully occupied with the game	Flow
6	I felt happy	Positive Affect
7	It gave me a bad mood	Annoyance/Tension
8	I thought about other things	Negative Affect
9	I found it tiresome	Negative Affect
10	I felt competent	Competence
11	I thought it was hard	Challenge
12	It was aesthetically pleasing	Immersion
13	I forgot everything around me	Flow
14	I felt good	Positive Affect
15	I was good at it	Competence
16	I felt bored	Negative Affect
17	I felt successful	Competence
18	I felt imaginative	Immersion
19	I felt that I could explore things	Immersion
20	I enjoyed it	Positive Affect
21	I was fast at reaching the game's target	Competence
22	I felt annoyed	Annoyance/Tension
23	I was concerned about the presented sounds	Attention to the presented sounds
24	I felt pressured	Challenge
25	I felt irritable	Annoyance/Tension
26	I lost track of time	Flow
27	I felt challenged	Challenge
28	I found it impressive	Immersion
29	I was deeply concentrated in the game	Flow
30	I felt frustrated	Annoyance/Tension
31	I felt like a rich experience	Immersion
32	I lost connection with the outside world	Flow
33	I felt time pressure	Challenge
34	I had to put a lot of effort into it	Challenge
35	I would like to play longer	Motivation
36	I paid attention to the presented sounds	Attention to the presented sounds
37	I found it hard to stop playing it	Motivation

Although the core module of the original GEQ consists of 33 items, four extra items No. 23 and 35 - 37 were added in this study to measure Motivation (No. 35 and 37) and Attention (No. 23 and 36): the participant's motivation to continue gameplay and the participant's attention to the sounds presented during gameplay. The added items were determined with reference to questionnaires in the post-game module and the GEQ's social presence module. For example, No. 36 and 37 were modifications of "I paid attention to the other" and "I found it hard to get back to reality" (No. 3 and 6 in the GEQ social presence module). Since the original GEQ is written in English, a Japanese version translated by a professional translator was used in this experiment.

In addition, participants were required to estimate the passage of time of the previous game session since the tempo of sounds affects the subjective sense of time [24]. In this experiment, participants were informed in advance that they would be asked to estimate the passage of time at the end of each session.

3.7.2 Post-FB Questionnaire

After all the FB sessions ended, all participants were required to answer the post-FB questionnaire about their perception of the presented sounds: "Did you perceive any difference between the presented sounds and your actual heartbeat," which was rated on a four-point Likert scale.

Although the items of the GEQ are rated on a five-point Likert scale, a four-point Likert scale was adopted here since the answer should be yes or no and its degree. A '3' in the five-point Likert scale means neither yes nor no, which is not a suitable answer.

4 Experimental Results

This section reports the statistical analysis results of the measurements collected through the experiment.

4.1 Self-Reported PX

To analyze the effect of different fHR feedback patterns on PX, a three-way repeated-measures analysis of variance (RANOVA) was performed using groups (A, B, C, and D) as a between-subjects factor and sessions (1, 3, and 5) and conditions (FB and CTL) as within-subjects factors, respectively. The 5 percent significance level was adopted. The three-way RANOVA found significant statistical differences in the following three components: Motivation, Negative Effect, and Annoyance.

4.1.1 Motivation

A three-way RANOVA found significant main effects of conditions ($F(1,36) = 17.4$, $p < .001$) and sessions ($F(2,72) = 85.2$, $p < .001$) in the Motivation component (No. 35 and 37). There was also a significant two-way interaction between groups and conditions ($F(3,36) = 10.2$, $p < .001$). Significant simple main effects of conditions were found both in groups A ($p < .001$) and B ($p = .006$), and significant simple main effects of sessions were shown in all groups ($p < .001$).

The changes in scores are summarized in Fig. 5. The scores measured in FB (FB scores) were significantly higher than the scores measured in CTL (CTL scores) both in groups A and B. A multiple comparison test revealed that the FB scores of group A stayed high throughout the sessions. On the other hand, the CTL scores of group A and the FB and CTL scores of the other groups decreased significantly as the sessions were repeated as shown in Fig. 5.

These results suggest that accelerating fHR feedback encouraged participants to continue video gameplay. In particular, the slowly accelerating feedback pattern of group A (+5 bpm/min) was more effective than the rapidly accelerating feedback pattern of group B (+10 bpm/min) because the FB scores of the third and fifth sessions significantly decreased in comparison with the first session ($p < .001$). Thus, there is an optimal acceleration tempo of fHR feedback for maintaining the player's motivation.

4.1.2 Negative Affect

On the Negative Affect component (No. 8, 9, and 16), main effects of conditions ($F(1,36) = 22.2$, $p < .001$) and sessions were significant ($F(2,72) = 28.2$, $p < .001$). While there were significant simple main effects of sessions in all groups ($p < .01$), a significant simple main effect of conditions was found only in group A ($p = .004$).

As can be seen in Table 2, the items of the Negative Affect component asked the degree of boredom. The FB scores of the third and fifth sessions were significantly lower than the CTL scores in group A ($p < .05$), which means that slowly accelerating fHR feedback of group A prevented participants from becoming bored.

4.1.3 Annoyance/Tension

A three-way RANOVA on the Annoyance/Tension component (No. 7, 22, 25, and 31) showed a significant three-way interaction ($F(6,72) = 3.92$, $p = .002$) and a significant main effect of groups ($F(3,36) = 6.95$, $p < .001$). There was a significant two-way interaction between groups and conditions ($F(3,36) = 3.87$, $p = .017$). Simple main effects of conditions were significant both in group B and D ($p = .026$, $p = .028$), whereas a simple interaction effect between conditions and sessions was significant only in group D ($p < .001$). The FB scores of group B seemed to increase as the session was repeated compared to CTL, and a multiple comparison test revealed that the FB score was significantly higher than the CTL score in the fifth session ($p < .05$). On the other hand, the FB scores of group D became significantly lower than CTL in the fifth session ($p < .05$).

There is a possibility that the rapidly accelerating fHR feedback of group B stressed the participants, whereas the slowly decelerating fHR feedback of group D relieved participants from stress. Although members of group A were also given an accelerating fHR pattern, their FB scores did not change significantly. This suggests that slowly accelerating fHR feedback did not put pressure on the participants.

4.2 Perception of Sounds

In the post-FB questionnaire, participants in all groups answered a questionnaire about whether or not they felt any difference between the presented sounds and their own heartbeat.

Fig. 6 shows the perception of sounds measured from the four groups. A one-way ANOVA was performed to examine the difference in perception of the presented sounds. There

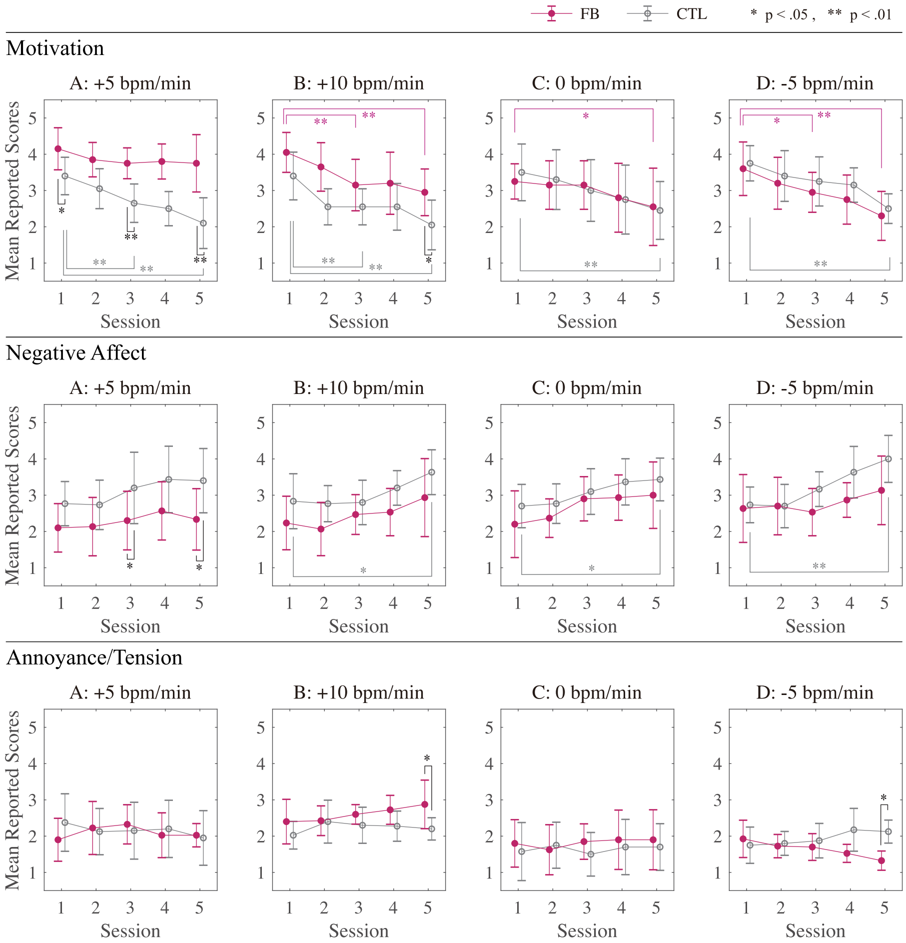

Fig. 5. FB and CTL scores of groups A, B, C, and D (top: Motivation, middle: Negative affect, and bottom: Annoyance).

was a significant main effect of groups ($F(3,36) = 5.81$, $p = .002$); the score of group B was significantly higher than the other groups. This means that participants in group B felt that the presented heartbeat-like sounds were unnatural. Although groups A and D were also given fHR feedback, their scores were not significantly different from group C who were given actual HR feedback, as shown in Fig. 6.

This result indicates that the participants in group B tended to notice the difference between fHR feedback and their actual HR since the accelerating tempo of group B was too fast, which might spoil the PX of the game.

4.3 Attention to Sounds

To investigate how much the participants paid attention to the presented sounds, a two-way RANOVA was performed using groups (A, B, C, and D) as a between-subjects factor and sessions as a within-subjects factor.

Fig. 7 shows the scores of the Attention component (No. 23 and 36) measured for all groups. The two-way RANOVA revealed significant main effects of sessions ($F(2,72) = 41.6$, $p < .001$) and groups ($F(3,36) = 10.4$, $p < .001$), and showed a significant interaction between groups and sessions ($F(6,72) = 3.02$, $p = .001$). A multiple comparison test revealed that the scores of groups A and B were significantly higher than those of groups C and D in the first session ($p < .001$). These suggest that false accelerating fHR feedback garnered strong attention of participants initially only when they were informed that the presented sounds reflected their actual heartbeat.

However, the scores of group B decreased more rapidly than those of group A. Players seemed to lose interest in the

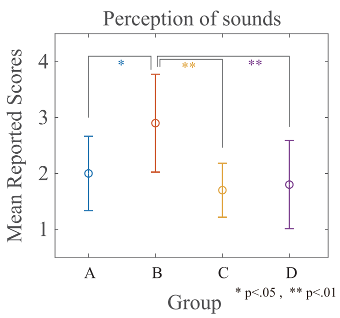

Fig. 6. Perception of sounds.

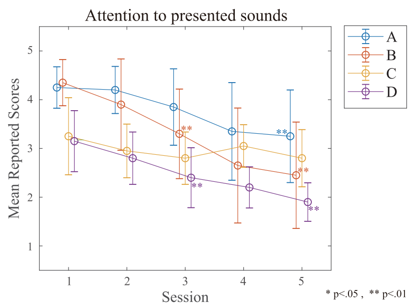

Fig. 7. Scores of Attention component.

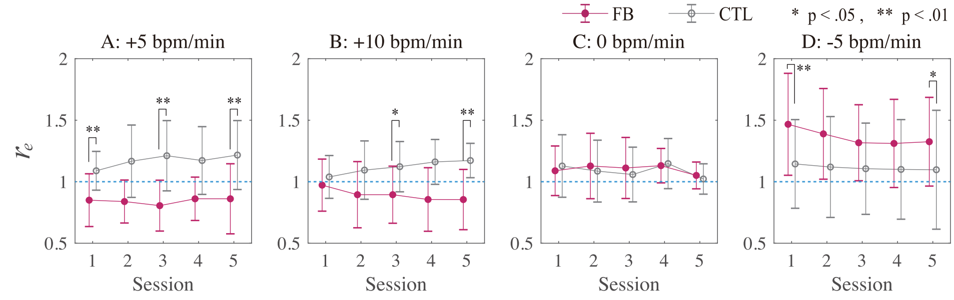

Fig. 8. The estimated time passage ratio r_e of groups A, B, C, and D.

presented heartbeat-like sounds, perhaps because they felt such rapid heartbeats to be unnatural.

4.4 Time Passage Estimation

The estimated passage of time was investigated. Time ratio r_e: $r_e = d_e/180$ was estimated, where d_e is the estimated passage of time [sec] of each session, and 180 indicates the play time [sec] of one game session. A three-way RANOVA was used to analyze r_e.

Fig. 8 shows the changes in r_e of all groups. The three-way RANOVA revealed a significant main effect of conditions ($F(1, 36) = 5.90$, $p = .020$), and showed a significant two-way interaction between groups and conditions ($F(3, 36) = 21.6$, $p < .001$). There was a significant simple interaction effect between conditions and sessions in group B ($p < .001$) and significant simple main effects of conditions in groups A, B, and D ($p < .05$).

The r_e in FB was lower than in CTL, both in groups A and B, which were given an accelerating fHR feedback (group A: $p < .001$ in the first, third, and fifth sessions, group B: $p < .05$ in the third session and $p < .001$ in the fifth session); the participants tended to estimate the passage of time to be shorter than the actual playtime. In contrast, the participants of group D, who were given a decelerating fHR feedback, tended to estimate the passage of time to be longer ($p < .001$ in the first session and $p < .05$ in the fifth session). This suggests that the tempo of the fHR feedback might affect the subjective perception of the passage of time during gameplay.

4.5 Measured Heart Rate

To investigate the effect of fHR feedback on the actual HR of participants, we analyzed the amount of rise in the HR within one session ΔHR using a three-way RANOVA since the evaluation of changes in absolute values of HR is difficult. The baseline of HR differs in every person, and HR has diurnal variation even in the resting state. ΔHR is defined as $\Delta HR = \mathrm{HR}_a - \mathrm{HR}_b$, where HR_a and HR_b are the average measured HR for 30 seconds before session end and after session start, respectively. Fig. 9 illustrates changes in ΔHR of the four groups. Significant main effects and significant interactions were not confirmed. fHR feedback did not affect actual physiological responses, and PX alteration was not related to changes in the actual physiological response.

4.6 Game Score

Fig. 10 shows the transitions in the game scores. Although a three-way RANOVA was performed on the game scores, significant main effects and significant interactions were not confirmed. Thus, the fHR feedback did not improve the playing performance of participants.

4.7 Gender Difference

We investigated gender differences in the effect of fHR feedback. Fig. 11 shows the gender difference in the Motivation component and the Negative Effect component in group A with slowly accelerating fHR feedback (+5 bpm/min). Significant main effects were not confirmed between males and females in any of the components or groups. Thus, it is concluded that there is no gender difference in fHR feedback.

5 Discussion

In this section, the experimental results and additional factors to be considered are discussed. In addition, we describe the limitations of this study.

5.1 PX Improvement Effect

According to the PX scores of the Motivation component, only participants in group A with slowly accelerating fHR feedback (+5 bpm/min) maintained their motivation to continue playing the game. The Negative Affect component also showed that only participants in group A were

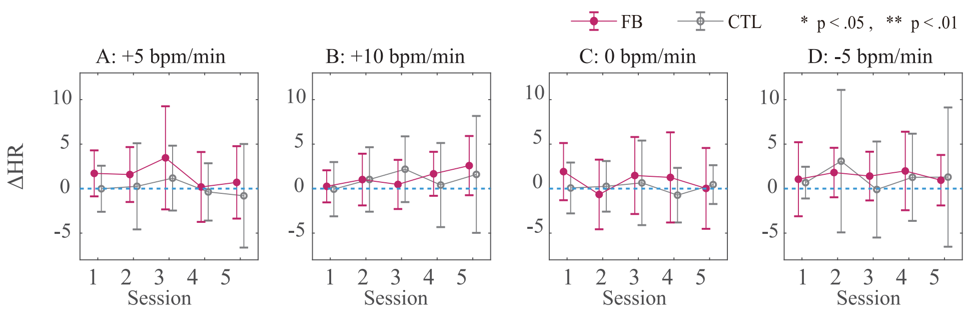

Fig. 9. Changes in measured HR.

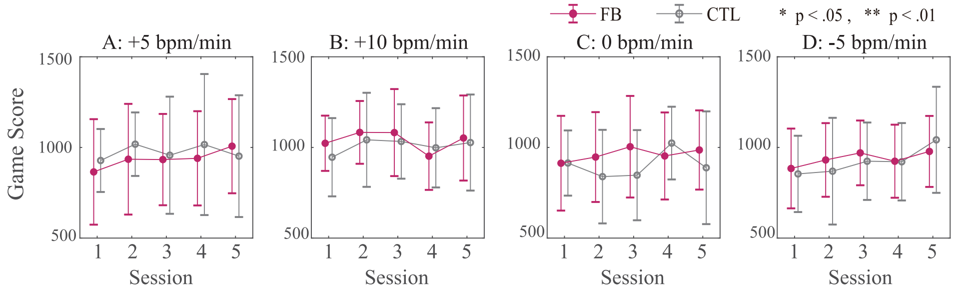

Fig. 10. Changes in game scores.

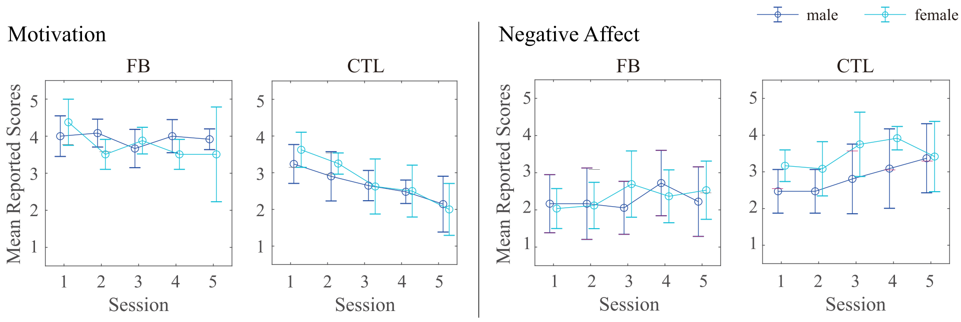

Fig. 11. Gender differences in FB and CTL scores of group A: Motivation (left) and Negative Affect (right).

prevented from becoming tired of the game. The Annoyance/Tension component showed that rapidly accelerating fHR feedback (+10 bpm/min) of group B annoyed and pressured the players, whereas slowly decelerating fHR feedback (−5 bpm/min) of group D seemed to suppress frustration. It is concluded that the slowly accelerating fHR feedback pattern of group A was the most effective for improving the PX of the game. Therefore, our hypothesis that accelerating fHR can improve PX of players was confirmed.

As described in Section 4.2, the participants in group B tended to feel some difference between the presented heartbeat-like sounds and their heartbeat. There is the possibility that such a sense of unnaturalness diminished the effect of fHR feedback on the PX. The acceleration tempo should be tuned carefully so that players do not notice a difference between the presented heartbeat-like sounds and their actual HR. Although the participants in group B also reported frustration with gameplay, such an effect caused by a rapidly accelerating fHR feedback may be useful in some game genres. For example, this effect could be used to induce the players' operation errors in action games.

In this experiment, participants were instructed, before gameplay, to estimate the passage of playtime at the end of each session. Such a time-estimation task is called prospective time estimation [25]. Previous studies have reported that an estimated passage of time is mainly affected by the amount of attentional resources allocated to the passage of time [26]; if players pay attention to the passage of time, their expected passage of time becomes longer than the actual passage of time.

The participants of groups A and B in FB tended to estimate a shorter passage of time than the actual time, while participants of group D estimated a more extended passage of time. There was no difference in the estimated passage of time between FB and CTL in group C. According to the self-reported PX scores, the players in groups A and B with accelerating fHR feedback maintained high motivation, which suggests that participants with accelerating fHR feedback were able to concentrate on the game. Thus, the participants of groups A and B in FB paid less attention to the passage of time.

5.2 Prior Knowledge About fHR Feedback

The two-factor theory indicated that emotions could be altered by giving false information related to the emotion as well as a false physiological response. Schachter and Singer confirmed this phenomenon with a drug administration experiment [6]. The emotion induced by the administered drug varied depending on the information about drug effects given before drug administration; some participants were given correct information about the drug effects, and some were intentionally given incorrect information. This indicates that emotions may alter according to prior knowledge about the environment.

In order to confirm the effect of prior knowledge about fHR, we performed an additional experiment. Ten healthy persons (six male and four female, 21.8±2.66 y.o., gameplay frequency 3.0±1.5) reproduced the experimental procedure of group A with slowly accelerating fHR feedback (+5 bpm/min); however, they were told that the presented heartbeat-like sounds are not correlated with their actual HR. This group was called group A'.

We conducted a three-way RANOVA. The between-subjects factor was groups (A and A'), and the within-subjects factors were sessions (1, 3, and 5) and conditions (FB and CTL). The three-way RANOVA found statistical differences in the Motivation (No. 35 and 37) and Negative Affect (No. 8, 9, and 16) components, which are shown in Fig. 12

In the Motivation component, the three-way RANOVA found a significant three-way interaction ($F(2,36) = 3.87$, $p = .030$), and showed significant main effects of conditions

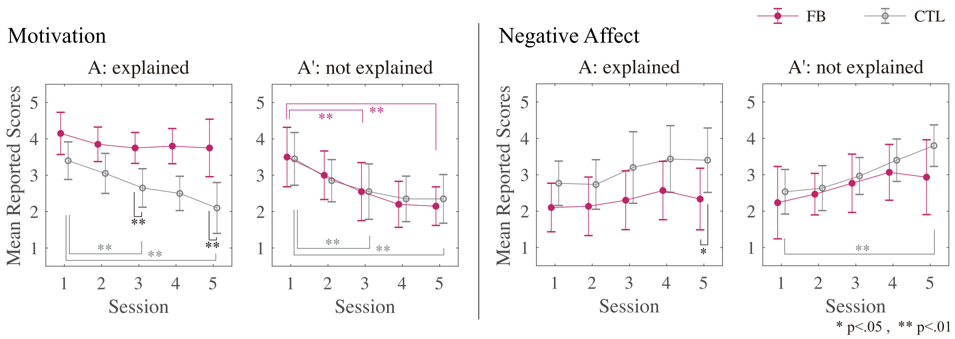

Fig. 12. FB and CTL scores of Motivation and Negative Affect measured from group A (left) and group A' (right). It was explained to the participants of Group A that the presented sounds are synchronized with their actual HR, and participants of Group A' were told that the presented heartbeat-like sounds are not correlated with their actual HR.

($F(1,18) = 18.2$, $p < .001$) and sessions ($F(2,36) = 40.0$, $p < .001$). The post-hoc tests found significant simple main effects of sessions both in groups A and A' ($p < .001$) and a significant simple main effect of conditions only in group A ($p < .001$). There was a significant three-way interaction ($F(2,36) = 3.87$, $p = .030$) in the Negative Affect component. Main effects of conditions ($F(1,18) = 17.0$, $p < .001$) and sessions ($F(2,36) = 15.2$, $p < .001$) were also significant. There was a significant simple main effect of conditions only in group A ($p = .003$) and significant main effects of sessions both in groups A and A' ($p = .044, p < .001$).

These results show that prior knowledge about the fHR feedback deteriorated the fHR feedback effect and that players should not be told about fHR feedback, in order to improve PX.

5.3 Effect of Sound Type

Stern *et al.* found that attention to a sound affects subjective experience even if the presented sound is unrelated to heart rate only when participants were instructed to pay attention to the presented accelerating sound [27]. They compared participants who were instructed to pay attention to the presented extraneous sound with those who were instructed to ignore the sounds in Valins's experiment. The participants who were instructed to pay attention to the accelerating extraneous sounds tended to evaluate pictures of opposite-sex persons to be more attractive, similar to participants who heard accelerating heartbeat-like sounds.

We performed another experiment in order to validate Stern's findings. Ten healthy persons (five male and five female, 21.5±2.22 y.o., gameplay frequency 2.7±1.5) participated in this experiment, who reproduced the experimental procedure of group A with slowly accelerating fHR feedback (+5 bpm/min) except for the presented sound type; a beep sound (1 kHz sine wave) was presented instead of the heartbeat-like sound. This group was called group A".

A three-way RANOVA was conducted to evaluate the effect of types of sounds of the fHR feedback on PX. The between-subjects factor was groups (A and A"), and the within-subjects factors were sessions (1, 3, and 5) and conditions (FB and CTL). Fig. 13 illustrates the comparison result, in which statistical differences in the Motivation and Negative Effect components were found. In the Motivation component, a significant two-way interaction between groups and conditions ($F(1,18) = 22.6$, $p = < .001$), and significant main effects of conditions ($F(1,18) = 33.8$, $p < .001$), and sessions ($F(2,36) = 12.3$, $p < .001$) were found. The post-hoc tests found a significant simple main effect of conditions only in group A ($p < .001$). The two-way interaction between groups and conditions ($F(1,18) = 4.88$, $p = .040$) in the Negative Affect component was significant. There were significant main effects of conditions ($F(1,18) = 9.99$, $p = .005$) and sessions ($F(2,36) = 16.1$, $p < .001$). A significant simple main effect of conditions was found only in group A ($p = .001$).

These results indicate that the sound type of the fHR feedback affected PX of the game; the beep sounds did not maintain the player's motivation, and the heartbeat-like sounds were more appropriate for improving PX than the beep sounds. Since group A" had the same feedback pattern as group A, the difference in sounds may affect the players' PX. Beep sounds are usually used for notification, such as error occurrence, in electronic equipment, and are not linked to physiological phenomena. According to Fig. 13,

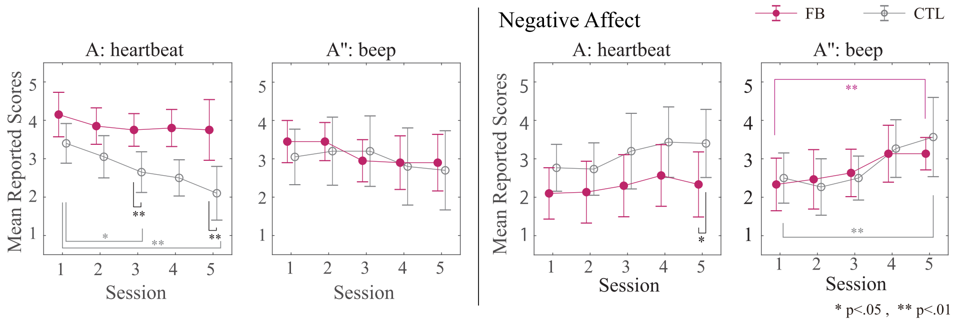

Fig. 13. FB and CTL scores of Motivation and Negative Affect measured from group A (left) and group A" (right). Participants in group A and A" heard the heartbeat-like sounds and the beep sounds, respectively.

there was no significant difference in the Motivation component between FB and CTL in group A". That is, the beep sounds may not attract the attention of participants.

Stern *et al.* insisted that attention to sound also affects subjective experience even if the presented sound is unrelated to physiological phenomena when an instruction to pay attention to the presented sound was given [27]. Truax's study [28] compared HR feedback with galvanic skin response (GSR) feedback. It is reported therein that fHR feedback is useful for altering subjective experiences, and that false GSR feedback affected experience only when the participants had been instructed that GSR responses were related to their affective arousal. This result suggests that participants need to have prior knowledge of the stimulated physiological responses. Since HR is a familiar physiological phenomenon to most people, prior instruction about HR feedback may not be required, and an instruction to pay attention to the presented sounds is not reasonable in video game playing. Thus, fHR feedback is suitable for improving the PX of video games, because such prior instructions are not desirable for gameplay.

5.4 Questionnaires

This study adopted the Game Experience Questionnaire for measuring PX of video game playing [8], which is the most widely applied questionnaires in games research. Law *et al.* reported that 147 articles explicitly used the GEQ between 2007 and 2017 [9]. Norman suggested that the GEQ seems reasonable and applicable in studying PX with video games, although he pointed out that its psychometric evaluations on reliability and validity have not yet been published by the GEQ developers themselves [29]. Law *et al.* evaluated the reliability and the validity of the GEQ, and indicated that the Challenge and Negative Affect components contain questionable items from the viewpoint of internal consistency [9].

We used the Negative Affect component for measuring the degree of boredom, although we did not analyze the Challenge component. As described in Section 4.1.2, our experiment showed that slowly accelerating fHR feedback of group A prevented participants from becoming bored based on the comparison result of the Negative Affect component. The efficacy of slowly accelerating fHR feedback of group A was demonstrated with other measurements such as the Motivation and the Attention components. Thus, the result of this study has not changed, even if the items of the Negative Affect component are questionable.

In this study, some components of the GEQ were not used, such as Flow and Immersion, because these components were not appropriate for measuring the effect of fHR feedback. Flow and Immersion are related to the imaginary world of the game and its story. However, the simple action game we used does not have a story or a unique world. Thus, we used components that can appropriately measure the effect of fHR feedback.

5.5 Limitations

The limitations of this study include the tested modality and game genre; we tried only a combination of auditory feedback and a simple action game in the experiment. The modalities used for the fHR feedback should be carefully considered when being introduced into other game genres. For example, since rhythm games require players to concentrate on sounds, it may be difficult to adopt auditory feedback in such a situation. Thus, the effect of the fHR feedback with various feedback modalities should be investigated.

6 Conclusion

The present work proposes a new game interaction system based on false heart rate feedback to improve the player experience of video games. The effect of fHR feedback on PX was investigated through an experiment. Six different types of fHR feedback patterns were tested, and the results show that slowly accelerating fHR feedback (+5 bpm/min) is best for improving PX. The experiment indicated that players need to recognize the presented sounds as reflecting their actual HR. In addition, heartbeat-like sounds are preferable to beep sounds for improving PX. This finding provides new principles on which the design of a video game interaction system using fHR feedback can be based.

Future works will evaluate whether fHR feedback is useful for improving the PX in other game genres. Moreover, fHR feedback using different feedback modalities will be investigated. A new sensing device that can easily and accurately measure the player's HR should be developed to realize a practical application of the proposed fHR feedback-based game interaction system.

Acknowledgments

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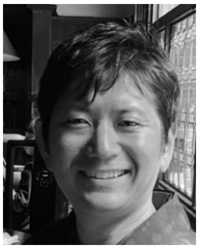

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