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ADVANTAGES AND DISADVANTAGES OF BIOFEEDBACK ON PLAYING PUZZLE GAMES

Fan Zhang and Hajime Murao

Graduate School of Intercultural Studies
Kobe University
1-2-1 Tsurukabuto, Nada-ku, Kobe 657-8501, Japan
{ zhangfan; hajime.murao }@mulabo.org

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Abstract. *This paper attempts to investigate whether stopping using biofeedback techniques applied to studying and entertainment after a long-period of use will make the participant's performance worse than before. At present, many research works focus on applying to biofeedback technique to entertainment or learning-support systems, so as to improve user's behavior by increasing excitement or engagement. However, our former researches showed that after a period of biofeedback experiment (for example, once a week for several weeks), participants' performance would become worse without biofeedback. We carried out a four times per month experiment on ten university students. As biofeedback might have different effects on different games, we used two kinds of tests, Sudoku and physics-based puzzle games. We obtained the biometric information of participants by brainwave sensor. During the experiment, a feedback music or environmental sound varied with the change of present engagement level of participants. For the first and the last time, the experiment was conducted without feedback in order to see whether there would be a change in participants.*

Keywords: Biofeedback, Learning-support system, Gameplay, Engagement, Withdrawal reaction

1. **Introduction.** Initially, biofeedback training was aimed at medical use, helping patients improve the ability to control their own physiological activities, such as helping patients with essential hypertension lower their blood pressure, helping patients with attention deficit hyperactivity disorder concentrate or patients with anxiety disorders relax. In order to increase the patient's motivation to accept the training, the training system is usually designed as a game, such as a game in which patients can move a piece of stone on the screen by concentrating on the stone. Since then, lots of biofeedback-based games have been designed for the sake of the health of people.

Furthermore, with the development of gaming industry and sensing technique, people started to combine biofeedback technique with games so as to make the game more fun. In the experiment of Munekata, she tried changing the number of enemies in the game in real time based on the information of skin conductance responses of participants collected during the game play [1]. Skin conductance responses can show to what extent the participants' hands get sweaty. When participants become nervous or excited, their skin conductance responses will increase.

Applying the biofeedback technique to the game makes the participants' skin conductance responses stronger and participants themselves feel enjoyed than before.

In the first person shooting game, Dekker and Champion tried to change some features of a horror game, such as game shaders, screen shakes, the new spawning points of non-playing enemies, and different elements of level like the speed of movement according to skin conductance responses and heart rate. All mentioned above proved that biofeedback could enhance the gameplay for different types of games [2].

Biofeedback can also improve the learning performance. As engagement level has proved having a great effect on the learning performance, researchers use electroencephalogram (EEG) to measure brainwaves instead of skin conductance responses to learn about participants' engagement levels in the related experiments.

Research conducted in this area usually uses learning support system to measure students' engagement levels by several means and gives the feedback to teachers in real time or after class to help teachers recognize students' conditions so as to improve teaching effect [3].

In the former studies, we designed a system in which the volume of environmental noises automatically changed with their engagement levels when they were writing reports. And we found that by using this learning support system, the decrease of engagement levels resulted from long-time studying could be slowed down. Besides, A. Barnea's research showed that SMR/θ feedback training for kids has a positive effect on their word recognition. Shin and Michiaki's research focused on the expression method of biofeedback. They compared the effect of biofeedback training on the engagement level when using audio with when using video. The result revealed that both of them were effective, and the effect of biofeedback did not rely on the receptors [4]. However, most researches just ask the participants to perform only one task during the experiment, such as the first person shooting game, focusing the attention on one point on the screen and word recognition test. So far what kind of task is unsuitable for biofeedback has not been studied, and the comparison of the effect of biofeedback under different tasks has not been made either.

However, in former experiments we found that when the students participated in an experiment without feedback after participating in the experiment with feedback for three times, their performances were not improved, but turned out to be worse instead. Without supervision, the participants seemed to be sleepy, less relieved, and found it more difficult to concentrate than before, which caught our attention. So far biofeedback has been considered a method without any disadvantages. Therefore, it is worth making clear what happened.

2. **Convergent/Divergent Thinking.**

Thinking process is usually considered divided into two types: convergent thinking and divergent thinking.

Convergent thinking is a process defined as following a peculiar logic to find a proper solution to the problem and finally leads to a single best answer. However, divergent thinking is a non-linear process. According to the problem situation, multiple possible answers are explored [5].

Some researches found that in different phases of writing, environmental noises also had different influences on participants. Researchers divided report writing into two parts, the generation of idea and the conclusion of idea, corresponding to convergent thinking and divergent thinking respectively [6]. Biofeedback using sounds as the medium may also lead to different performances because of convergent thinking and divergent thinking.

In this study, we chose Sudoku puzzle that needs participant to concentrate and find out the unique solution as the case of convergent thinking. For divergent thinking, we used physics puzzles with multiple solutions for experiment.

Sudoku puzzle is a logic-based number-placement puzzle. The participant needs to fill a 9×9 grid with digits and make sure that each column, each row, and each of the nine 3×3 sub-grids that compose the grid contain all of the digits from 1 to 9. Usually some cells are already filled with digits, which are called hints. The more hints there are, the easier the puzzle becomes. Each puzzle has a unique solution.

Physics puzzle is a kind of game that has been very popular in the mobile game market in recent years. In a two- or three-dimensional space a with realistic physics system,

	6	7	2		4	1		
8				6				2
	5			7		3	4	
		1		3	2			
4	7	2			1	5		
5		6	7					
1	2	3	4	5	6	7	8	9
6	4							

FIGURE 1. An example of the Sudoku puzzle

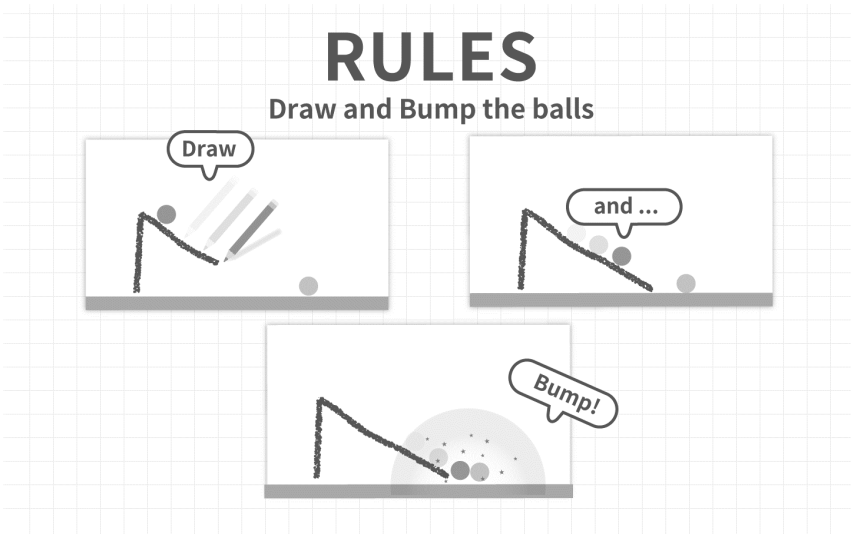

FIGURE 2. An example of the physical-based puzzle game called "Brain Dots", which needs to make two balls together by drawing a line

participant needs to finish the puzzle by creating or moving some objects in this space. This kind of game usually includes only a few hints, and each puzzle has multiple solutions.

3. **System Design.** In this study, we use a non-invasive wireless EEG device called Emotiv EPOC to obtain the EEG signal. And a plug-and-play heart-rate sensor called Pulse Sensor to obtain the heart rate and the heart rate variability (HRV) for another research.

This experimental system obtains the EEG information of participants through Emotiv EPOC and estimates their present engagement level. The commonly-used engagement formula $\beta/(\alpha + \Theta)$ and engagement score provided by Emotiv SDK will be used in the estimation of engagement level. In the engagement formula, the Beta wave (β) represents when the subject state of mind is active. The Alpha wave (α) represents when the subject state of mind is relaxed and the Theta wave (θ) represents when the subject state of mind is sleepy or dreaming.

In the experiment, we try different types of feedbacks to help participants achieve higher engagement scores, and the value of engagement formula $\beta/(\alpha+\Theta)$ will also be recorded. We use environmental noise as feedback of engagement level to participants. The volume is initially set to 50% of max volume. When the engagement level of participant rises, the volume of environmental noise will gradually decrease to 10%, for the complete disappearance of noise may cause distraction instead. However, when the engagement level of participant decreases, the volume will be increased to draw the participant's attention. The relationship between volume and engagement score is determined by a sigmoid function.

At the same time, the participant will be asked to wear a Pulse Sensor on the earlobe to obtain the information of the heartbeat of participant during the experiment. Time taken for each participant to complete each puzzle will be all recorded. The whole process of the experiment will be recorded to assess the participant's performance.

4. **Participants.** Participants will be selected from university students. The participants will be asked to fill in an online questionnaire before they participate in the experiment. In the questionnaire, whether the participant has an experience or good at relating games will be investigated, and a timed Sudoku puzzle and a timed physics puzzle will be included to test their puzzle-solving abilities. Finally, about ten college students who share a similar level of ability will be selected for the experiments.

5. **Evaluation.** The participants will sit in a soundproof room, and be divided into two groups. First, the participants in Group A (participants A, C, E) will be asked to take a rest for two minutes and then do the Sudoku puzzles for twenty minutes. Next, they will be asked to rest for another five minutes and do the physics puzzles for twenty minutes. By contrast, the participants in Group B (participants B, D) will follow the same steps but not in the same order. They will be asked to do the physics puzzles first instead of Sudoku puzzles. All the participants are required to finish the puzzles as quickly as possible, and informed that the quickest participants will be awarded in advance. Each participant participates in a 60-minute experiment once a week for four times. In the fourth experiment, we applied biofeedback to the experiment only for the first five minutes, and then the volume of environmental noise was fixed at 50%. However, the participants were still informed in advance that the experiment would be carried out with biofeedback.

6. **Discussion.** After each experiment, we got the data like this (Figure 3). This is the trend chart of the engagement level in one of the experiments. In this experiment, we can see that the engagement level was decreasing with time, so we used the linear regression slope to show the trend of engagement level of the participant in this experiment.

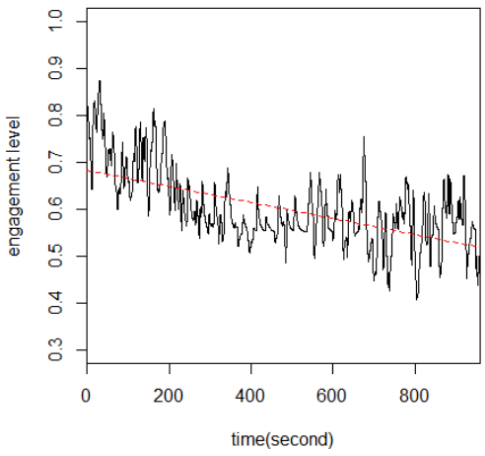

FIGURE 3. One of the engagement level data of experiment

Figure 4 shows the trend of engagement levels of five participants (A, B, C, D, E) in each experiment. We can see that in the Sudoku puzzles, the engagement level of each participant in the second time is higher than in the first time without exception. However, in the last time, the engagement levels of most participants declined. For example, three of them decreased to the level in the first time experiment. This suggests that feedback is possibly effective in the Sudoku puzzles. What is more, since participant D did not have a clear understanding about the rule of Sudoku puzzles until the third time (no repeated

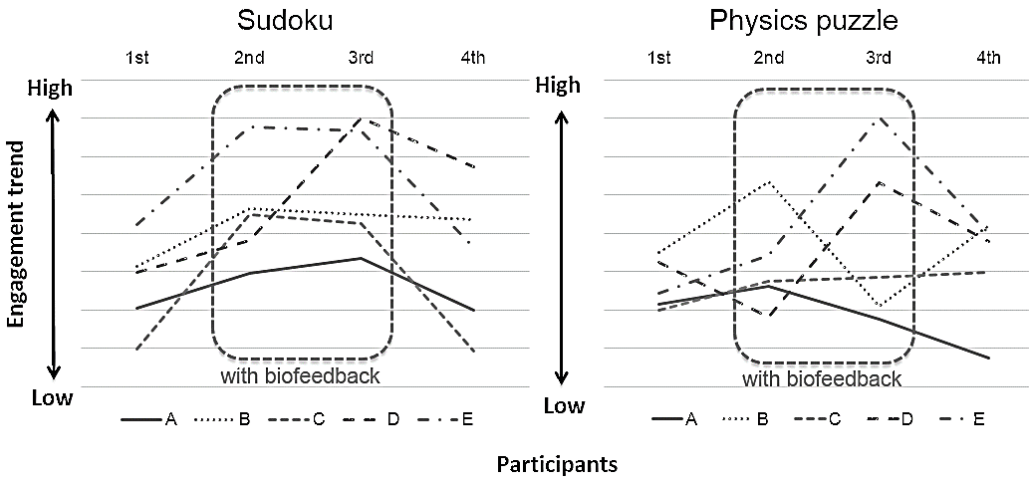

FIGURE 4. Engagement trend of each participant

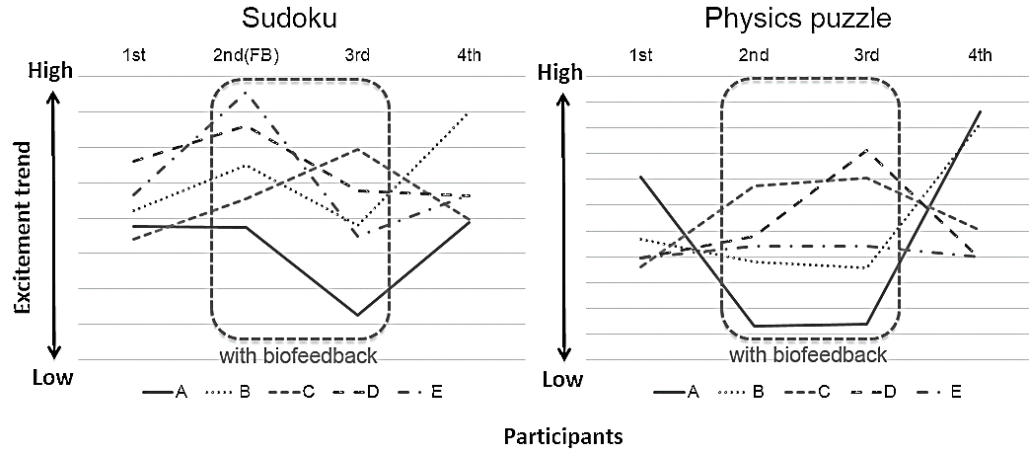

FIGURE 5. Excitement trend of each participant

numbers in any 3×3 grid), according to the figure we can imagine how difficult it was for him to solve the problem at that time.

On the contrary, we cannot see any patterns in the physics puzzles.

Figure 4 shows the trend of the excitement levels of five participants in the experiments. Here we can find that the increase of the excitement levels of most participants in the second time experiment conducted with feedback is much bigger than in the first time experiment that without feedback.

However, in the third time experiment, the excitement levels of four out of five people all decreased and even became lower than in the first time experiment. In the fourth time experiment without feedback, the excitement levels of three participants increased again, while the other one remained the same. In the second time experiment, the participants learned about biofeedback for the first time, and this helped increase their excitement levels. However, in the third time experiment, the excitement level decreased. From the interview with the participants after the experiment, we learned that participants A, B, D, E all considered themselves became more concentrated than before in the fourth time (yet it did not appear to be true according to the data). Participant C did not realize the biofeedback during the experiment.

Besides, we cannot see any patterns in the physics puzzles either. What is more, after the final experiment, participants A and B both reported that they felt themselves got more concentrated than before, while the other three participants did not realize any

changes. During the whole research, no one realized that there was no feedback in the final experiment.

7. **Conclusion.** In this study, we aim at seeking the similarities and dissimilarities of the effect of biofeedback under convergent thinking and divergent thinking. Therefore, we apply puzzle games to the experiment. As a new attempt, we use Sudoku puzzles and physics puzzles standing for convergent thinking and divergent thinking in experiment on the feedback of engagement. We found that applying biofeedback to Sudoku puzzles could increase engagement level, but it did not have the same effect when playing the physics puzzles. During the physics puzzle games, participants' engagement level would obviously decrease when they were waiting for the results to be displayed. So the engagement level turned out to be more easily influenced in this irrelevant stages than by their own degree of distraction and concentration. As a result, participants were not sure whether they were distracted or concentrated in the physics puzzle game. So it would make participants feel insensitive about the noise feedback.

Furthermore, this study also attempts to find out the reaction of participants after the biofeedback for increasing engagement levels is interrupted. Results showed that stopping the feedback would eliminate the effect like increasing engagement level. No matter the participants themselves realized or not, there was no evidence to prove that stopping the feedback would make the participants become less concentrated than before in this experiment.

As the starting/game over stages of the game would be an interference, we will try to integrate biofeedback into the game in the future works, so that we can reduce the negative influences from irrelevant stages such as game loading and waiting.

Besides, wearing the Emotiv EPOC for over half an hour will cause pain and discomfort. And this made it impossible for us to test the effects of feedbacks for a longer time. So we consider to use more appropriate devices for future experiments.

In this research, we could not perform statistical analyses for there were not enough participants. We need more experiments to prove our opinion.

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