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BRAIN-COMPUTER INTERFACE (BCI) BASED LEARNING SUPPORT SYSTEM PROVIDING THE FEEDBACK ON LEARNER'S EMOTIONS AND ITS EFFECT

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Abstract. *This study is based on a hypothesis that learners can improve learning efficiency or learning experience by the development of their self-control of emotions inspired by the biofeedback therapy. To verify, we developed a real-time feedback system to feedback learner's engagement score to themselves while learning, and tried different feedback methods in experiment. As the result, the experiment has proved that the feedback in a proper way will have a positive effect on the learner's involvement in learning and learning experiences with users' self-reports and EEG data from users, which means greater possibilities for personal Learning Support Systems.*
Keywords: Brain-computer interface, Passive BCI, Engagement, Learning

1. **Introduction.** Concentration, which affects learning efficiency and learning experience, is very important in learning. However, it is difficult for learners to recognize the level of concentration by themselves. In the recent studies of educational technology, researchers usually use learning support system to measure students' engagement levels by several means such as Accelerometer [1], Image Analytics [2] or Electroencephalography (EEG) [3], and give the feedback to teachers in real time or after class to help teachers recognize students' conditions so as to improve teaching effect. However, the three kinds of education support systems mentioned above all need teacher's participation. So it cannot be carried out in students' self-study.

To solve this problem, we developed a method based on bio-feedback/neurofeedback. Bio-feedback is originally used in the treatment of essential hypertension and attention deficit/hyperactivity disorder (ADHD) [4,5]. However, as it helps improve patients' self-control of engagement, bio-feedback has also been considered to have the possibility of application in the field of education as well [6].

However, the treatment of ADHD using bio-feedback takes several weeks of training to show the effect. Furthermore, if we applied this method to the field of education directly, the visual feedbacks used in bio-feedback therapy (such as a number or bar on monitor) would also disturb the learners when they are learning. Therefore, we developed an education support system which can function in learning immediately without preparation (long-time training) in advance, and inform the learners of their concentration levels with less direct interference.

In the experiment, we used audio recordings feedback instead of visual feedback or tactile feedback to reduce the negative impact. In this period, we asked four students to write reports with education support system at regular intervals for two months, trying different methods such as using piano note, environmental noise, playing chord/discord, and controlling the volume or rate of background music for the participants to show them their own levels of engagement, and made a comparison between these different audio methods.

In Sections 2 and 3, we introduced the EEG device and engagement measurement used in this experiment. In Section 4, the architecture of our education support system and steps of the experiment were stated. In Section 5, we described four kinds of feedback methods which had been tried in experiment. Finally, in the last section, we came to the conclusion of the experiment and showed our future work.

2. **Device.** In this study, we use a non-invasive wireless EEG data acquisition and processing device called Emotiv EPOC. This device consists of 14 electrodes based on the international 10-20 locations to obtain the EEG signal and these channels. The device is also easy to wear. Participants can move their head freely to some extent in experiment for the data is transferred by Bluetooth. Moreover, the low cost of it is also appealing. Therefore, Emotiv EPOC now has already been widely used in researches such as education and entertainment [7,8].

FIGURE 1. The Emotiv EPOC headset

3. **Engagement Measurements.**

1. EEG. EEG can analyze and record electrical signals of neuronal activities (brainwaves). Compared with fMRI, its temporal resolution is higher and cost is lower. Also, it is more portable. The EEG is typically described in terms of rhythmic activity and transients. The rhythmic activity is divided into bands by frequency. Different bands of brainwaves are found associated with different mental states. For example, alpha waves (8-13Hz) correspond to a state of relaxation. Beta waves (13-30Hz) correspond to focused concentration. Theta waves (4-7Hz) correspond to deeper state of relaxation. Based on these researches, a formula used to determine the level of engagement was put out in 1995 and now is still in use [9].

$$E = \frac{\beta}{\alpha + \theta} \tag{1}$$

2. The Emotiv Affective Suite. EEG is very sensitive to vibration. Any slight vibration will cause loud noises which interfere with brainwaves and introduce error into the measurement. Therefore, this kind of experiment needs the participant to keep his head at a fixed location to avoid errors. However, this rule may put stress on the participants. By contrast, the Emotiv EPOC we used examines the vibration of the head by using acceleration sensor, and even when the participants move their head freely (to a certain degree), it can also provide an accurate result of engagement rate by its own algorithm.

3. Subjective assessment. The participants may report their levels of engagement during the experiment by point scoring and evaluation.

In order to get smooth and stable input signals for self-feedback, in this research we used engagement/boredom score (Es) provided by Emotiv EPOC as input signals. And subjective assessment is also used to see whether the data gained is appropriate.

4. **System Architecture.** In this system, Emotiv EPOC will transfer the information of brainwaves to a computer by Bluetooth, and turn the measured level of engagement (engagement score) into relevant audio signals for feedback.

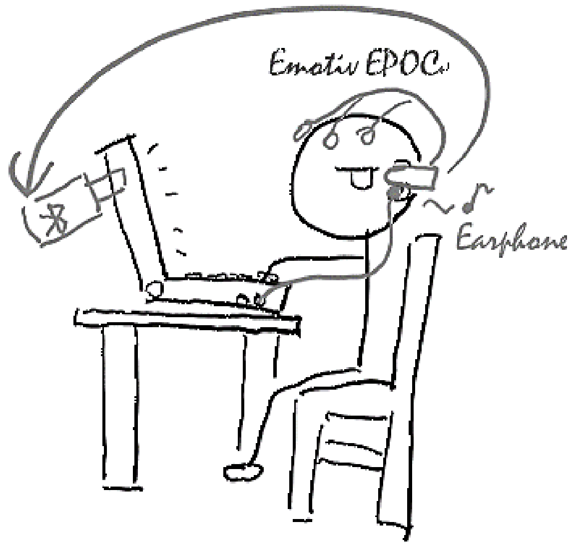

FIGURE 2. Participant is using the Emotiv EPOC when learning.

Participants chosen for this experiment were four students (3 males and 1 female) at Kobe University. Several kinds of feedbacks were tested weekly at fixed time. The process is listed below.

1. The steps of this experiment will be described to the participants, and the meaning of audio signals for feedback in this experiment will also be explained.
2. Participants will be asked to wear the Emotiv EPOC separately for 40 minutes, and concentrate on school report as much as they can.
3. At the end of the experiment, we will have a 10-minute-long interview with each participant.

Repeat each method of feedback (which will be further explained later) 3∼5 times for each participant. If some method of feedback is reported to be "very bad" by more than half of all participants, this method will be stopped.

5. **Feedback Methods.** Concerning how to send feedback to learners by audio, we employed four methods of feedback in this experiment and tested each of them.

5.1. **Musical note.** Engagement score will be matched one by one with the 1st to 88th note on the piano. In every few seconds, note is played to make the participants have a direct feeling about their level of engagement. However, here the interval is not fixed. It is influenced by the speed of change. For instance, when the engagement score changes greatly, the frequency of feedback will increase from once in three seconds to several times in one second.

The results of music note feedback are shown in Figure 3. The X-axis is time and Y-axis is engagement score (Es). Dotted lines stand for linear regression.

Monotonic and continual piano note makes the participant feel quite uncomfortable. When the engagement score decreases, the declining scales (Scale) as feedback will cause the participants to feel frustrated. And the frustration will make the condition aggravated,

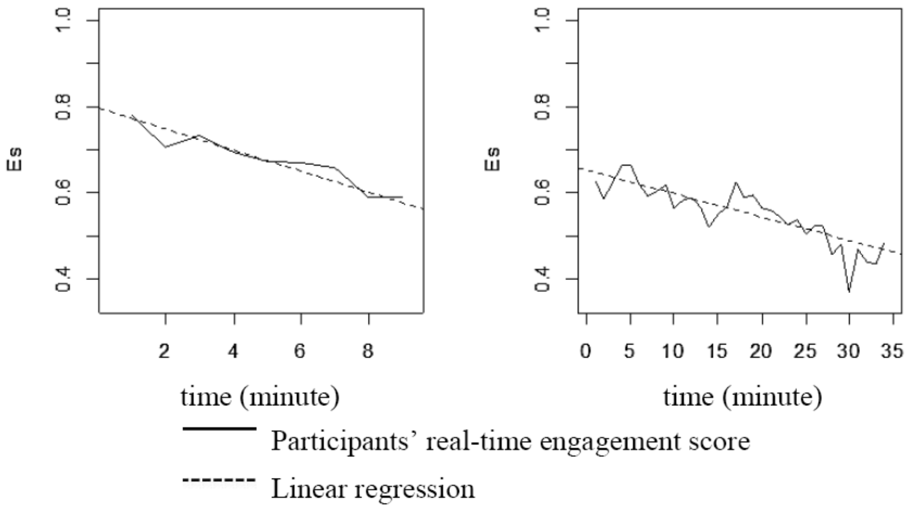

FIGURE 3. Two cases of participants' engagement score during the experiment using musical note feedback

in which it becomes more difficult for participants to concentrate and engagement score will further decrease.

5.2. **Chord/discord.** The chord will be played when engagement score increases, while the discord is played when engagement score decreases. The degree of increase will be represented by major and minor. We expect that the pleasant and unpleasant feeling caused by chord and discord will help participants have a better control of their engagement levels.

However, in the experiment, the same problem which occurred in the experiment of musical note before appeared again. The negative effect of discord, causing frustration and reducing the engagement level of the participants, is much bigger than the positive effect of chord. The participants said that they felt difficult to concentrate.

For this reason, we removed the negative feedback and repeated the experiments. However, without the contrast, the result will turn to be similar to that of controlled trial.

5.3. **Music.** We assume that music can bring comfort to the learner, but the music that is too soft or slowed down will make them uncomfortable. The participants were asked to listen to the new age music. And when their Es decreased, the volume or rate of music decreased as well. When their Es increased, the volume or rate of music returned to normal. The degree of the increase and decrease of the volume or rate of music was adjusted by a sigma function in real time.

$$f(Es_{t0}) = \frac{1}{1 + e^{2\frac{avg(Es_t)-Es}{\max(Es_t)-\min(Es_t)}\log\frac{1-L}{L}}} \tag{2}$$

Here, Es_t is the engagement score from time $t0$ to time t. L is the tuning parameters. In this experiment, we set t as 1 minute and adjusted L manually by experience.

According to the report of participants, the assumption was proved to be true that slowing down the music will make them uncomfortable. However, when they succeed in concentrating, the sense of satisfaction will distract them from concentration. Moreover, the experiment by controlling the volume has the same problem. Participants tend to be distracted as music returns to normal. From the data, we can see that whether we control volume or rate, the results turn out to be similar.

5.4. **Environmental noise.** Learning from the experiences of other feedbacks, we began to use environmental noise which includes less information in order to avoid distraction caused by music. Here the volume of noise will increase when the Es of participants

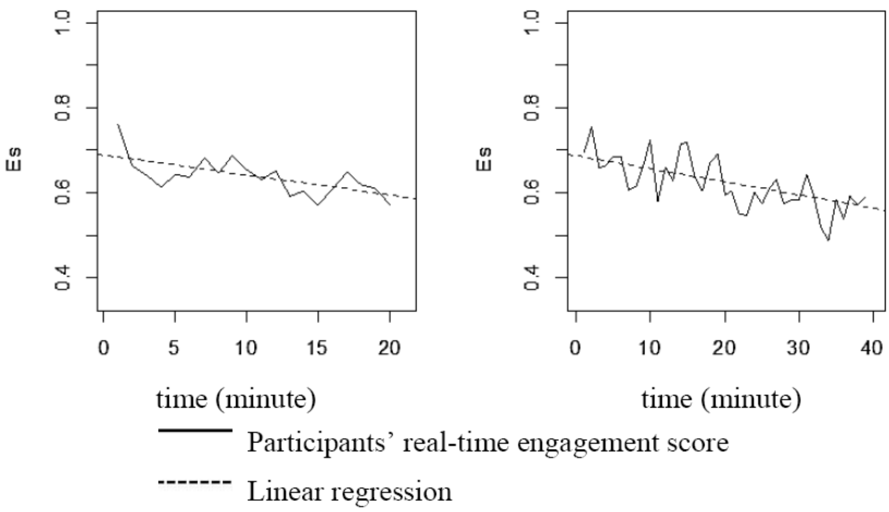

Figure 4. Two cases of participants' engagement score during the experiment using music feedback. The left figure stands for volume-control and the right figure stands for rate-control.

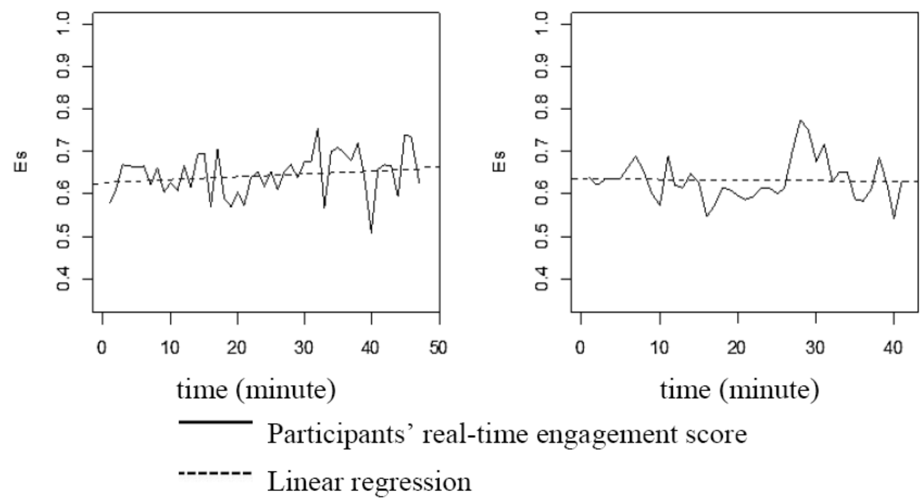

Figure 5. Two cases of participants' engagement score during the experiment using environmental noise feedback

decreases, and reduce (finally to nothing) when the Es increases. This time we tried to keep the intensity of satisfaction and frustration brought by feedback within proper limits by adjusting the parameter of sigma function.

The subjective evaluation of this method is better. For example, at the end of experiment, some participants said that they could keep on doing the homework for a bit longer than before. And some other participants felt that they finished task in less time. Besides, data also proved that the tendency that Es decreases with time has been weakened. So these two points showed that this method is more effective than the methods mentioned before.

5.5. **Controlled trial.** In order to evaluate the effect of the feedback properly, we implemented two controlled trials. One is carried out in a voiceless environment, while the other one is carried out with the same noise audio that we used in the environmental noise test before.

We found that the engagement score declined with time whether in a voiceless environment or not.

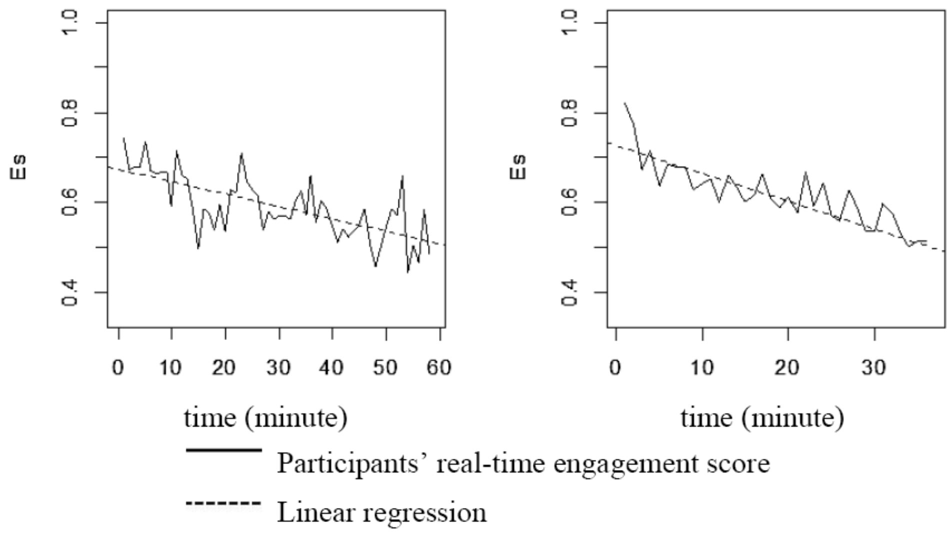

FIGURE 6. Participants' engagement score in controlled trial. The left one stands for voiceless environment. The right one stands for noisy environment.

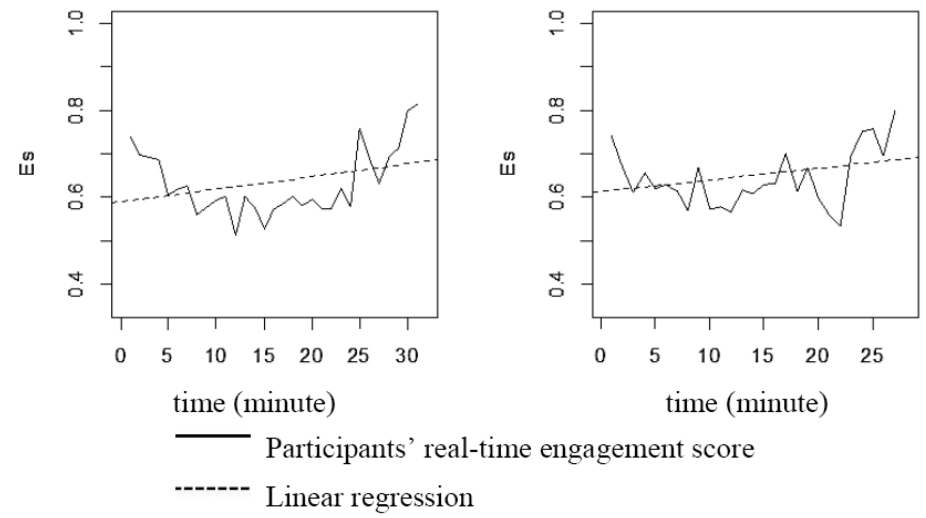

FIGURE 7. Participants' engagement score in chat/SNS trial. The left one stands for voiceless environment. The right one stands for noisy environment.

We repeated the experiment again, but this time the participants were asked to chat online or browse SNS instead of learning. As the result, their engagement score did not generally decline with time.

6. **Conclusions.** Although we were still not able to effectively improve the level of concentration in learning by this method, slowing down the process of distraction caused by long-time studying has been proved to be possible. In Figure 8, we can see that the difference between the slope of linear regression of engagement score in music feedback group (or note feedback group) and controlled trial is not significant. Besides, according to the participants, the chord/discord caused direct interference, so this feedback method was also abandoned. Finally, we found that the slope of linear regression of engagement score in noise feedback group was higher than controlled trial and had significant difference $(P = 0.002077)$.

As a result, the experiment has proved that the feedback in a proper way will have a positive effect on the learner's involvement in learning and learning experiences with

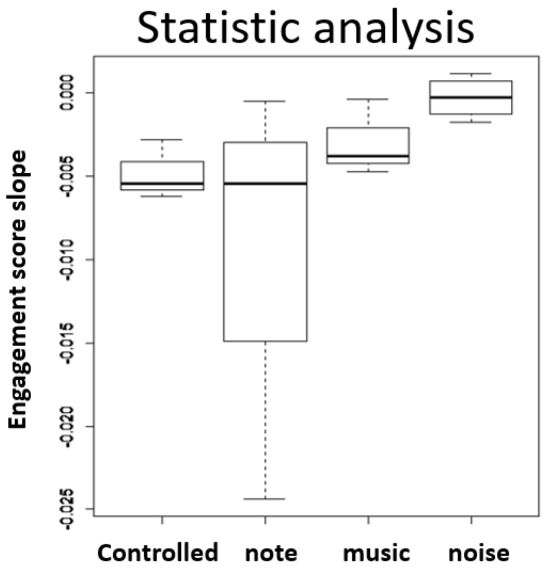

FIGURE 8. Statistical analysis of the slope of linear regression of engagement score

users' self-reports and EEG data from users, which means greater possibilities for personal Learning Support Systems.

In addition, we found that the feedback which contains less information (even the melody) so as not to interfere with learning was very important. And the control of intensity of frustration and satisfaction brought by negative feedback and positive feedback should also be paid attention to. The effect will be greatly reduced if any of them becomes too low or too high.

Now parameters used in the experiment can only be adjusted manually from experience. And we hope it can be adjusted automatically by algorithm in the near future.

Furthermore, we realized that wearing the Emotiv EPOC for over 50 minutes would cause a great deal of pain and discomfort. For the pain had made it impossible for us to conduct experiments testing the effects of feedbacks for a longer time, we consider using more appropriate devices for future experiments.

It is also worth noting that during all of the controlled trials carried out after several times of environmental noise feedback tests, the participants experienced varying degrees of sleepiness. We supposed that the practice of learning with feedbacks will lead to the decline in self-control in the same situation. However, this assumption seems to be contrary to the definition of bio-feedback: "behavioral training aimed at developing skills for self-regulation of brain activity" [10]. Now we still do not have enough experimental data to prove whether it has universal validity. More experiments are needed to confirm this point.

REFERENCES

[1] K. Kosaka, S. Nomura, T. Iwaki et al., A review supporting system for storytelling by using 3D cameras and accelerometers, *SIG Technical Reports Information Processing Society of Japan*, pp.1-8, 2011.

[2] A. Masayuki and M. Toshiki, Evaluation of the concentration level of the learner of the class by real time image information analysis, *Research Report of JET Conferences*, pp.149-156, 2006.

[3] D. Szafir and B. Mutlu, ARTFul: Adaptive review technology for flipped learning, *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, pp.1001-1010, 2013.

[4] B. Thomas, *Introduction to Quantitative EEG and Neurofeedback: Advanced Theory and Applications*, 2nd Edition, Academic Press/Elsevier, Amsterdam, 2009.

[5] D. Kong, J. Huo, H. Fu et al., Controlled study on long-term effect of EEG biofeedback on ADHD, *Journal of Medical Forum*, vol.28, no.2, pp.20-22, 2007.

[6] K. Omura, Prospect of neurofeedback in the field of education, *Bulletin of Yamagata University*, vol.15, no.1, pp.67-84, 2010.

[7] M. Andujar and J. E. Gilbert, Let's learn!: Enhancing user's engagement levels through passive brain-computer interfaces, *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, pp.703-708, 2013.

[8] B. S. Goldberg, R. A. Sottilare, K. W. Brawner et al., Predicting learner engagement during well-defined and ill-defined computer-based intercultural interactions, *Affective Computing and Intelligent Interaction*, Springer Berlin Heidelberg, pp.538-547, 2011.

[9] A. T. Pope, E. H. Bogart and D. S. Bartolome, Biocybernetic system evaluates indices of operator engagement in automated task, *Biological Psychology*, vol.40, nos.1-2, pp.187-195, 1995.

[10] H. Heinrich, H. Gevensleben and U. Strehl, Annotation: Neurofeedback-train your brain to train behaviour, *Journal of Child Psychology and Psychiatry*, vol.48, no.1, pp.3-16, 2007.