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Affective Measurement

Improvement of BCI operation accuracy by the VR human bod...
Brain-computer Interface, Virtual Reality, Motor Imagery,...

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Improvement of BCI operation accuracy by the VR human body motion feedback

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Abstract: This paper proposes a brain-computer interface virtual reality (BCI-VR) to improve brain-computer interface (BCI) operation accuracy using hand animation feedback by virtual reality. At first, we thought event-related desynchronization/synchronization (ERD/ERS) response is easier to detect in the case of imagining of hand than in the case of imagining of arm since the corresponding area of the motor cortex of the hand is larger than that of the arm. As a result, we assumed that BCI operation accuracy is improved. Thus, we compared the effect of imagining of making fists and of imagining of conventional arm raising. Also, we conducted an experiment to operate the BCI to find BCI accuracy of operation, and a sense of agency (SOA) was obtained using the seven-point Likert scale. The results demonstrated that the imagine of making fists was higher than the conventional imagine of arm raising in both the average of operation accuracy and the SOA. However, the Mann-Whitney's U test depicted no significant difference between the accuracy of the imagining of making fists and of imagining of arm raising. Additionally, it was found that there was a positive correlation between BCI operation accuracy and SOA. Therefore, motor imagery of making fists is considered to be good for improving the accuracy of the BCI operation but it needs to be verified. It was also suggested that the accuracy of BCI operation could be improved if the SOA could be obtained. In the future, we will continue to develop BCI-VR to improve the BCI.

Key words Brain-computer Interface, Virtual Reality, Motor Imagery, Sense of Agency, Feedback

1. INTRODUCTION

Generally, the brain-computer interfaces (BCIs) are computer technologies that use brain wave response similar to human psychology. The electroencephalographic (EEG) event-related desynchronization/synchronization (ERD/ERS) response is observed directly above the motor area during an intentional musculoskeletal movement motor imagery [1] .

The interface performance of the BCI includes the number of objects being operated (number of switches), time from intention to operation (response speed), and operation accuracy (correct answer rate). Wada et al. have subjects trained to recognize hand movement images from a first-person viewpoint and when the emerging ERD exceeds a threshold, the exoskeleton robot attached to the hand is synchronized with the images and multi-sensory feedback. Their result demonstrated that ERD intensity increased significantly before and after the training [2].

Further, our research group proposed a body movement feedback that raises arms using virtual reality (VR) easily obtains a sense of agency (SOA) and improves operation accuracy than the bar graph animation or cube floating movement [3]. However, the operation accuracy was 65% in the best case and 40% even after 3 months of training, so detecting the ERD/ERS response with high sensitivity remained an unsolved problem.

However, homunculus showed by Penfield et al., knows that the area of the corresponding area of the motor cortex is larger for the hands than for the arms [4]. We thought ERD / ERS response is easier to detect in the case of imagining of hand than in the case of imagining of arm since the corresponding area of the motor cortex of the hand is larger than that of the arm. As a result, we thought BCI operation accuracy is improved

Therefore, in this paper, we trained the imagine of making fists, created BCI, and verified the effect. We obtained the number of correct operations per specified number of times and calculated the ratio as the operation accuracy. Furthermore, we measured the subjective evaluation of whether the SOA was obtained using the seven-point method.

2. METHOD

2.1 Brain-computer interface virtual reality

Brain-computer interface-virtual reality (BCI-VR) is a computer system for controlling the VR using the EEG, which was developed by our research group [3]. The system was developed by combining Emotiv (EEG headset) with Unity. The screen shown was a feedback to the subject, and it was possible to give feedback as if they were raising their arms by imagining raising arms without raising their arms (Figure 1).

In the BCI-VR of this paper, the EEG measurement device was replaced with g.USBamp biosignal amplifiers
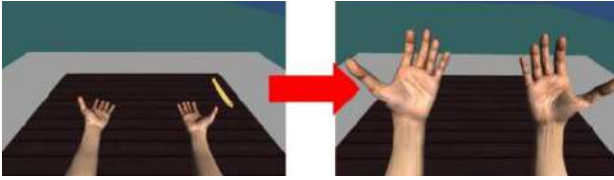
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Figure 1: Arms animation feedback (Raising arms)

(Guger Technologies) and the analysis program was composed of Simulink/MATLAB (Math Works). The feedback part used Sixense Unity Plugin provided by Unity Asset Store (Figure 2).
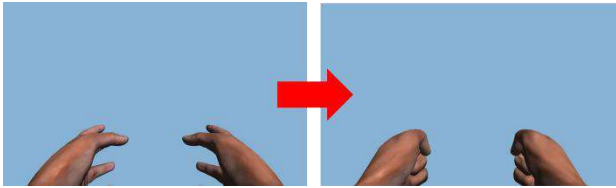

Figure 2: Hands animation feedback (Making fists)

Figure 3 shows when imagine of making a fist is extending a bar to the right in screen, and when resting is extending to the left . In this study, we used this to construct feedback. In the BCI-VR, when the bar is extending to the right, the hand animation is making fists, and when the bar is extending to the left, the hand is opened (rest). Since it is not yet revealed how to convert the bar size to hand animation, the bar size was ignored, and only the direction was reflected as feedback. Although the hardware and software differ greatly from the conventional system, the procedure up to the BCI operation is the same.
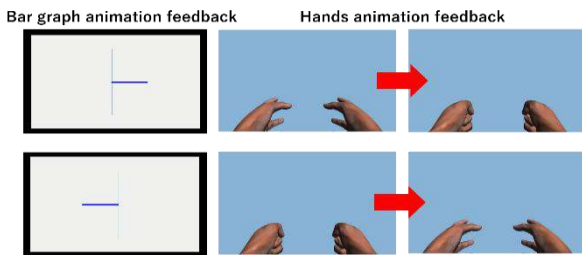

Figure 3: Correspondence between Bar graph feedback and Hands animation feedback

2.2 Offline classification

Offline classification is required for online feedback. First, wear an EEG cap with electrodes on the head. After practicing the gripping exercise, acquire the teacher data. The teacher data is the two states of imagining of making fists or imagining resting and the corresponding EEG. According to the trigger signal of the EEG, run consisting of 40 trials (i.e., 20 trials per class rest/motor imagery presented in a randomized order) was conducted without feedback.

Next, a discriminant model is calculated using linear discriminant analysis (LDA) with the teacher data. The g.BSanalyze (Guger Technologies software) was used to

create the discriminant model. The discrimination model can classify unknown EEG data online as imagine rest or motor imagery by the BCI. The recorded brain activities in this initial non-feedback run were used to set up a subject-specific classifier for the classification in the following feedback runs.

2.3 Online classification

In online classification, FB is performed using the discrimination model created in the offline classification. The feedback to the subject is shown on the screen as a body animation (Figure 2). When the discrimination result is to imagine rest, the hands' animation moves from the closed state to the open state (if it is fully opened, it does not move anymore). When the discrimination result is motor imagery, the hands animation moves from the open state to the closed state (if it is completely closed, it does not move anymore). The opening and closing speed of the hands' animation was locked.

2.4 EEG Recording

Brain signals were recorded by g.USBamp biosignal amplifiers from four EEG electrodes that were placed over the primary sensorimotor cortex according to the international 10–20 system (F3, P3, F4, P4). A reference electrode was mounted on the right ear and a ground electrode on the forehead. A bipolar derivation method was used, and the differences between the conventional and the proposed BCI-VR, including the electrode arrangement were summarized (Table1, Figure4).

Table 1: BCI-VR(previous study & current study)

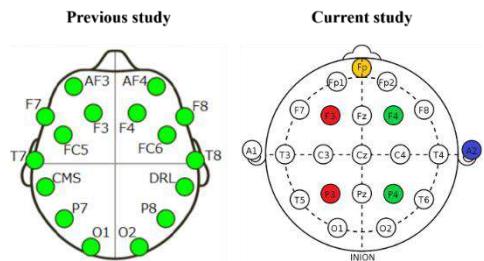| BCI-VR	Previous study	Current study
Device	Emotiv	g.BCI System
Electrode	16	6
3D Model	Arms	Hands
Imagery Task	Raising Arms	Making Fists
HMD	√	×

Figure 4: EEG electrodes

2.5 Subjects

Five healthy subjects (5 males, age twenties) participated in this experiment. The first experience BCI operation for Sub.5 among Sub.1-5. Subjects were given

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the details of the experiment in advance, and they consented to join the experiment before experimenting. Subjects reach under the display. They look like their arms connected to the hand on the screen. Subjects cannot see their own hands. Sub.6 and Sub.7 are the previous study subjects [3]. They imagined of raising arms.

3. EXPERIMENT

Subjects sat in a chair and the experimenter mounted the EEG electrodes to subjects. The experiment consists of preliminary measurement, training, measurement, and questionnaire (Figure 5).
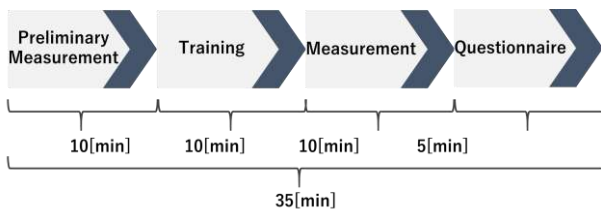

Figure 5: Experimental paradigm

3.1 Preliminary Measurement

In the pre-measurement, a discriminant model for discriminating the state imagine of rest and imagine making fists shown in Section 2.2 (Offline classification) making fists the according to hands' animation displayed on the screen. Instructions were letters on the screen (Figure6) .
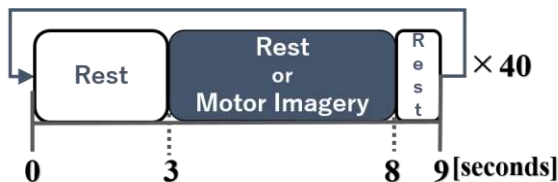

Figure 6: Trial flow

3.2 Training

In this training, motor imagine while making fist according to the instructions. The instruction method and instruction contents are the same as in the pre-measurement. Using the discriminant model created in advance measurement, feedback was performed by discriminating EEG into two states imagine of rest or imagine of movement. The experiment was performed to give the subjects a concrete image of BCI's operating.

3.3 Measurement

In the measurement, feedback is performed only by imagine the motion of the making fists. Except for this point, it is the same as training.

3.4 Questionnaire

We asked subjects about the SOA when they operated BCI by as a psychological index.

Q) Did you feel that you were moving the operation target (hand model)?

Subjects scored Q based on the seven-point Likert scale, where 1 denoted, "Didn't feel such thing at all" and 7 denoted, "Felt it strongly" And the opinions and impressions about the experiment were freely described.

3.5 Evaluation

The BCI operation accuracy was determined by the true operation, and defined as the correct rate (CR) operation. The CR [%] is a correct rate in the confusion matrix, which is derived from the average of each correct response against intended imageries. It is calculated based on the number of times when the subject response and the instruction match (1). The I1:R1, I1:R2, I2:R1 and I2:R2 are numbering in the confusion matrix, which are numbers of trials on the BCI experiment. I1:R1 is that subject rest state when instructed to rest state, I1:R2 is that subject make fists when instructed to rest state, I2:R1 is that subject rest state when instructed to make fists and I2:R2 is that subject make fists when instructed to make fists. (Table2) Motor Imagery is when the hand animation is determined to be making fists, and Rest is when the hand animation is determined not to making fists.

$$CR[\%] = \frac{1}{2}\left(\frac{I1:R1}{I1:R1+I1:R2} + \frac{I2:R2}{I2:R1+I2:R2}\right) \times 100 \ldots (1)$$

4. RESULTS

From the measurements, the number of rests for the rest instruction and the number of motor imagery for motor imagery instruction for total subjects is shown (Table 2). The CRs are tabulated with bars graph. The painted-out bar graph is CR to subjects (Sub.1-5) imagined of making fists and the border of the bar is CR to subjects (Sub.6-7) imagined raising arms (Figure 7). The average of CR was 54 [%] for imaging of making fists and 40 [%] for imaging of raising arms. The Mann-Whitney U test for the CRs of imaging of making fists or raising arms showed a p-value of 0.31 and no significant difference.

Table 2: Total of imagery accuracy on making fists (N = 5)

			Subjects responses	
			Rest state	Making fists
			R1	R2
Intended imagery	Rest state	I1	40	60
	Making fists	I2	32	68

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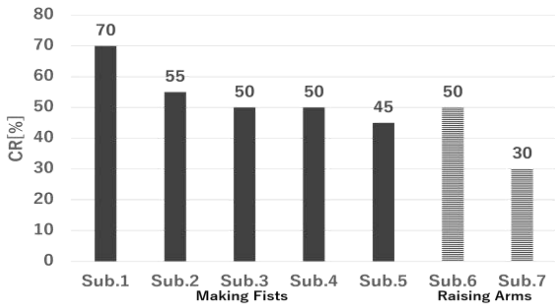
Figure 7: Each subject of the correct rate (N = 7)

The results of the questionnaire are shown for each subject in the experiment (Table 3). The average of the SOA was 5.8 for imaging of making fists and 3 for imaging raising arms. The correlation between CR and SOA were determined (Figure 8). The correlation is 0.53, and the coefficient of determination was 0.27.

Table 2: Each subject's sense of agency(N=7)

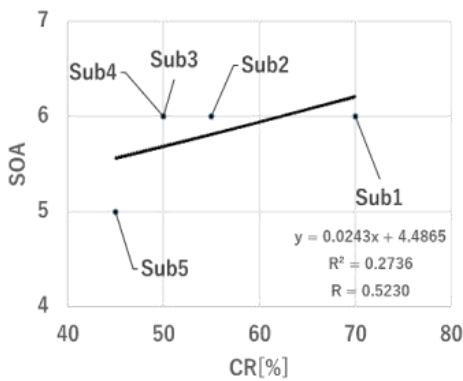| Making Fists					Raising Arms	
Sub1	Sub2	Sub3	Sub4	Sub5	Sub6	Sub7
6	6	6	6	5	2.8	4.2

Figure 8: Correlation between
CR and SOA (Max = 7, Min = 0) (N=5)

5. DISCUSSION

The results demonstrate that the Mann-Whitney U test for the CRs of imagining of making fists or raising arms showed a p-value of 0.31 and no significant difference. However, the average of CR was 54 [%] for imagining of making fists and 40 [%] for imaging of raising arms. The average value of CR shows that the imagining of raising arms is higher than imaging of making fists. Thus, in the BCI operation, it is considered that motor imagery using hands can improve the CR, but further verification is needed in the future.

The average of the SOA was 5.8 for imaging of making fists and 3 for imaging raising arms. Therefore, it can be said by the psychological index that subjects could perform operating BCI as desired by the imagining of making fists more than imagining of raising arms. However, the subject's SOA is high regardless of the subject CR. The criteria for recognizing that BCI operation is possible to vary greatly between subjects. Therefore, subjects with low CR may feel that they were able to operate as intended if they moved a little as instructed. The correlation between CR and SOA was 0.52, which found to be positive. Therefore, it is assumed that it is better to obtain SOA to improve CR.

From the free description of the questionnaire and the comments from the subjects, it was found that the BCI operation required considerable concentration. Therefore, it is desirable to have an environment in which taking a lot of breaks reduces the burden on the subjects and allows them to concentrate. Furthermore, there was an opinion that if a different instruction was given before and after, the later instruction would be influenced by the previous instruction, making it difficult to switch. Looking at the subject's data, we confirmed that many people were resting or imagining of the motor continuously. In the future, we intend to improve the above problems while developing feedback using hand animation and aim to further improve the operation.

6. Conclusion

In this paper, to improve the BCI operation accuracy, we created a BCI-VR using body motion feedback by VR and verified the effect of the imagining of making fists. The ratio was calculated as the operation accuracy, and the SOA was obtained and measured subjectively by the seven-item method. As a result, the imagine of making fists was higher than the conventional imagine of raising arms in both the operation accuracy and the SOA. Therefore, it is considered that the hand-holding motion of the hand is good for improving the operation accuracy in the motion imagine during BCI operation.

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