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Investigation of Optimal Mental Task Combinations for EEG-Based Brain-Computer Interface (BCI)

J.-H. Lim[1], H.-J. Hwang[1], C.-H. Im[1]
[1]*Hanyang University, Seoul, Korea*

Correspondence: C.-H. Im, Department of Biomedical Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul, 133-791, Republic of Korea. E-mail: ich@hanyang.ac.kr

Abstract. A number of EEG-based brain-computer interface (BCI) studies have adopted well-known mental task combinations (e.g., left- vs. right-hand motor imagery) without finding an optimal mental task combination most appropriate for each individual. In this study, we compared classification accuracy for various mental imagery task combinations with the aim to provide a reference useful for determining individual-specific mental tasks. Nine participants performed eight different mental imagery tasks during EEG recordings. We estimated classification accuracies for all possible mental task combinations, when the numbers of mental tasks were two, three, and four. Results showed that certain combinations of motor and non-motor imagery tasks tended to result in higher classification accuracy than combinations of solely motor imagery tasks. On the other hand, brain activity patterns elicited by "mental multiplication," "left hand motor imagery," and "geometric figure rotation" were not well discriminated when these tasks were performed simultaneously. Moreover, performing similar type of mental tasks at the same time did not result in high classification accuracy.

Keywords: BCI, EEG, various mental imagery tasks, optimal combination of mental tasks

1. Introduction

Brain-computer interface (BCI) systems employ various mental imagery tasks, e.g., motor imagery, spatial navigation, auditory imagery, and mental calculation. However, a considerable number of individuals (15-33%) have difficulty generating distinct task-related brain activity patterns for given mental tasks, thereby failing to achieve classification accuracy high enough to be used for practical BCI applications. One of the solutions to circumvent the BCI illiteracy issue would be using individualized mental task combinations instead of using a fixed set of mental tasks. In the present study, we investigated a variety of issues to be considered in selecting individual-specific mental task combinations: i) What are the best and worst mental task combinations? ii) Which mental task is the most distinguishable and which is the least? iii) Do combinations of motor imagery tasks show higher performance than other combinations? iv) Can mental tasks of a similar kind be used together?

2. Material and Methods

2.1. Experimental Procedures

Nine healthy participants took part in this study. Seven participants performed each mental task 20 times, and two participants (P5 and P9) performed each mental task 15 times. A total of thirty electrodes were used for the EEG recording. We conducted a series of experiments with eight different mental tasks (task A: mental character writing, task B: mental multiplication, task C and D: right and left hand motor imagery, task E: mental singing, task F: geometric figure rotation, task G: mental subtraction, and task H: tongue motor imagery). According to the experimental paradigm, the participants carried out the designated mental task for 10 s for each trial.

2.2. EEG Data Anaysis

The extracted raw EEG signals were spatially filtered using a common average reference (CAR) to compensate for common noise components. Spectral band powers and their inter-hemispheric asymmetry rations were calculated to construct feature vectors. The frequency bands were separated into five sub-frequency bands: theta (4-7 Hz), alpha (8-13 Hz), low beta (14-20 Hz), high beta (21-30 Hz), and gamma (31-45 Hz). We estimated classification accuracies for all possible combinations of mental tasks, when the numbers of mental tasks were two, three, and four. The numbers of the possible combinations were 28 (= ${}_8C_2$), 56 (= ${}_8C_3$), and 70 (= ${}_8C_4$) for two, three, and four mental tasks, respectively. We used the leave-one-out cross validation (LOOCV) method to evaluate classification accuracy, considering the relatively small number of task trials. In every cross-validation step, the sequential forward feature selection (SFFS) method was used to select the best feature subset for the training dataset, at which time the number

of selected features was limited to less than 10 to prevent over-fitting. The remained trial was then classified by a linear discriminant analysis (LDA) classifier trained using the selected best feature subset.

3. Results

Table 1 presents the best and the worst five combinations of mental tasks for each number of mental tasks. The mental task combinations including task A (mental character writing) and task C (right hand motor imagery) showed high classification accuracy regardless of the number of mental tasks. On the contrary, the mental task combinations, including tasks B and F, tasks D and F, and tasks B and D, showed relatively low classification accuracy (task B: mental multiplication, task D: left hand motor imagery, and task F: geometric figure rotation). As a result of counting the number of times that each mental task was included in the best or worst five mental task combinations, tasks A (mental character writing) and C (right hand motor imagery) were most frequently included in the best five mental task combinations. In contrast, tasks B (mental multiplication), D (left hand motor imagery), and F (geometric figure rotation) were most frequently included in the worst mental task combinations.

To investigate how well a set of different motor imagery tasks can be distinguished from each other compared to other mental task combinations, we ranked the mental task combinations consisting of solely motor imagery tasks. In most cases, combinations of motor imagery tasks did not yield high classification accuracy, and their rankings were about average (17th for left hand vs. right hand, 22th for left hand vs. tongue, 13th for right hand vs. tongue).

We also ranked the combination of mental tasks B (mental multiplication) and G (mental subtraction) among all possible combinations of two mental tasks (28 (=8C2)). In most cases, the combination of two arithmetic calculation tasks showed poor classification accuracy compared to the other combinations (ranking: 21st for P1, 7th for P2, 18th for P3, 16th for P4, 8th for P5, 19th for P6, 24th for P7, 24th for P8, and 1st for P9).

Table 1. *The best and worst five mental task combinations when the numbers of mental tasks were two, three, and four, respectively. Motor imagery tasks are shown in underlined italics type (Tasks C, D, and H).*

Ranking	The number of the best mental tasks						The number of the worst mental tasks					
	2		3		4		2		3		4	
	MC	CA (%)	MC	CA (%)	MC	CA (%)	MC	CA (%)	MC	CA (%)	MC	CA (%)
1	(A, *C*)	95.00 (±2.32)	(A, B, G)	92.03 (±7.34)	(A, *C*, E, F)	84.72 (±8.81)	(B, F)	74.44 (±21.17)	(B, *D*, F)	74.26 (±20.19)	(*D*, E, G, H)	70.78 (±12.72)
2	(A, G)	93.88 (±3.65)	(A, *C*, F)	89.63 (±8.77)	(A, B, *C*, G)	84.67 (±11.14)	(*D*, F)	79.35 (±16.14)	(*D*, E, F)	76.23 (±20.53)	(B, *D*, E, F)	71.52 (±18.92)
3	(G, H)	92.59 (±7.07)	(A, *C*, *H*)	89.25 (±4.92)	(A, B, G, *H*)	84.67 (±10.12)	(*D*, E)	79.43 (±17.73)	(*D*, E, *H*)	76.85 (±16.82)	(*D*, E, F, H)	73.19 (±19.12)
4	(*C*, E)	91.85 (±6.30)	(A, B, *C*)	89.19 (±4.99)	(A, B, *C*, *D*)	84.58 (±7.75)	(B, *D*)	79.72 (±18.53)	(B, *D*, E)	77.96 (±14.51)	(B, *D*, F, G)	73.19 (±18.89)
5	(B, *C*)	91.75 (±8.02)	(A, *C*, E)	88.76 (±7.84)	(A, *C*, *D*, *H*)	84.49 (±11.56)	(B, *H*)	83.98 (±14.82)	(B, *D*, *H*)	79.44 (±20.84)	(B, *D*, E, *H*)	74.95 (±16.62)

4. Conclusion

Many BCI studies have introduced various kinds of mental tasks. However, because some participants cannot produce discriminable brain activity patterns for specific combinations of mental imagery tasks (BCI illiteracy), it is an important research topic to find the optimal mental task combination most appropriate for each individual. In the current study, in order to provide a useful reference for the selection of optimal mental task combinations, we investigated the suitability of a variety of mental task combinations for mental-imagery-task-based BCI.

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