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# A Quantitative EEG Measure of Inter-subject Synchronization for Human error analysis

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## 1. Introduction

In this paper, we propose a novel quantitative electroencephalogram (EEG) measure by exploiting inter-subject synchronization for human error analysis. We hypothesized that when the operators perform the same task, the dynamics of teamwork increases. The time evolutions of EEG for two subjects were observed by performing a picture puzzle and neural synchronization was calculated by bispectral analysis [1]. While conventional researches related to inter-subject synchronization or team cognition use qualitative analysis or indirect brain activity analysis, the proposed method for neural synchronization is a direct approach to analyzing EEG [2,3]. In the experiments, we confirm the usefulness in terms of how well the proposed method reflect the inter-subject synchronization.

## 2. Experimental Methods

We designed the experiment to demonstrate on the hypothesis that the neural synchronization increases when the operators perform the same task.

### *2.1 EEG recordings*

This study included 6 healthy volunteers over 20 years old. EEG was recorded at two monopolar channels in the prefrontal region (Fp1 and Fp2 with the reference electrode in A1 of the international 10-20 system [4]) by a BIOS-Single (BioBrain Inc., Daejeon, Korea) with a sampling frequency of 250 Hz and we used the EEG signal from right parietal area. A tenth-order Butterworth filter were used to remove components above 50Hz from the EEG signals.

### *2.2 Study Design*

We explored the inter-subject synchronization by letting two subjects view three minutes of picture puzzles. The experiment is carried out in three steps, ‘baseline’, ‘task’ and ‘rest’. The ‘baseline’ and ‘rest’ sections are performed for 90 seconds with closed their eyes. The ‘task’ section is performed for 180 seconds after the ‘baseline’ section. In the ‘task’ section, total six picture puzzles are presented at intervals of 30 seconds.

## 3. Proposed Methods Exploiting Neural Synchronization

In the inter-subject synchronization analysis, we used the bispectral analysis [1]. The bispectral approach is a method of measuring the degree of phase coupling between spectral components. The bispectrum is defined as

$$B_{f_L - f_H}(f_i, f_j) = \left| \sum_l X_l(f_i) X_l(f_j) X_l^*(f_i + f_j) \right| \quad (1)$$

where $X_l$ is the spectral component, $X_l^*(f_i + f_j)$ indicates the conjugate of $X_l(f_i + f_j)$ and the subscript $l$ refers to epoch number.

Synch Fast Slow (SFS) [1,5] which is the ratio of the bispectrum in total band versus gamma band of EEG can be obtained as following

$$SFS = \log \frac{\sum_{f_i, f_j} B_{0.5-47Hz}(f_i, f_j)}{\sum_{f_i, f_j} B_{40-47Hz}(f_i, f_j)} \quad (2)$$

Fig. 1 presents an example of SFS for EEG data. The upper part of the figure shows the EEG signal which is combined the EEGs of the two subjects, and below shows the time evolution of SFS; two vertical dashed lines indicate the time points of the start and end of the task. In the figure, SFS shows higher values than ‘rest’ section in ‘task’ section.

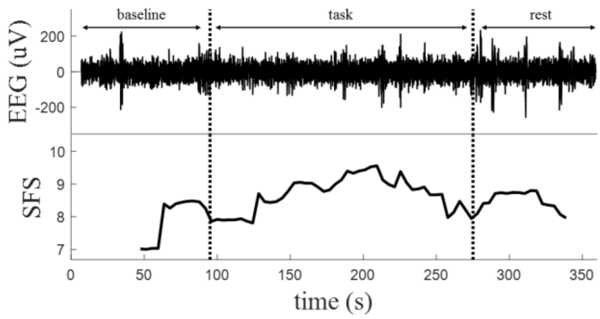


Fig. 1. Example of SFS using EEG data (the two vertical dashed lines indicate the start and the end of the task)

## 4. Results

The efficacy of the proposed methods was confirmed in a total of 6 subjects. For the data analysis, the epoch size, $w$ and the sliding step, $\Delta$ are set to 4 sec. A total of eight epochs (32s) are added to calculate the SFS.

Fig. 2 shows the results of SFS for 3 groups. The value of SFS in the ‘task’ section is shown to be higher than the other sections.

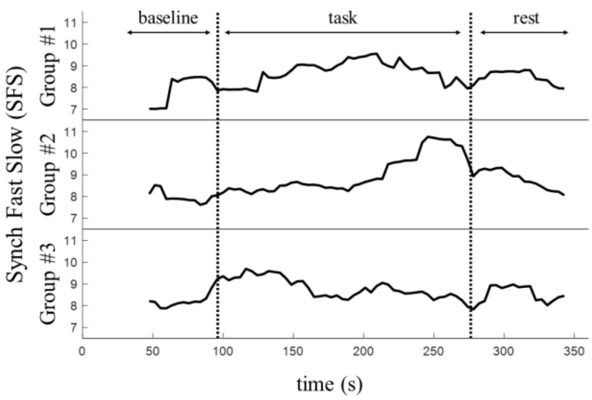


Fig. 2. The time evolution of SFS for three groups. A group consists of two subjects.

The mean and variance of SFS for three group are shown in Table I. In all groups, the mean value of SFS in the 'task' section is highest.

Table I: Outcomes of SFS for three group
(mean ± variance)

| Group # | baseline | task | rest |
|---|---|---|---|
| 1 | 7.5926 ± 0.5022 | 8.6907 ± 0.2617 | 8.3641 ± 0.1270 |
| 2 | 8.0137 ± 0.0652 | 8.8790 ± 0.7768 | 8.8365 ± 0.3610 |
| 3 | 8.2237 ± 0.0965 | 8.8340 ± 0.1927 | 8.4263 ± 0.1759 |

In order to remove the subject dependency, the results of the SFS were normalized with the mean value of the section 'rest' for each group. The boxplots of 3 groups are expressed with median values and quartiles (25%-75%) of averaged values for each section, which are shown in fig. 3.

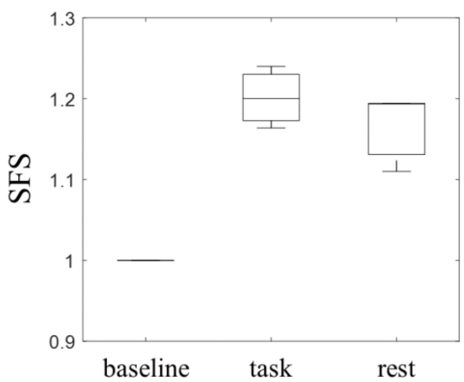


Fig. 3. Boxplots of the normalized and averaged results for each section. The middle line is the median value. The middle line is the median value.

## 5. Conclusions

The changes in inter-subject synchronization level was examined by proposed quantitative EEG measure. The bispectral analysis was used to detect the neural synchronization of two subjects. The effectiveness of the proposed method was validated through the experimental results. Although we confirmed the possibility of the proposed method as the detector of inter-subject synchronization, the experimental design needs to set more specific for measuring neural synchronization. Future work will be based on solving this limitation.

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