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EEG Correlation Patterns of Hypothesis-Generating in Undergraduate Students' Generation of Scientific Knowledge

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ABSTRACT

The purpose of this study was to test the notion that the inter-individual difference in hypothesis-generating is presumably detected by differentiating subjects' EEG correlation patterns of the prefrontal lobes. To test the notion of the inter-individual difference by EEG analysis, eight healthy undergraduate volunteers' EEG signals on the prefrontal lobes were recorded during hypothesis-generating and resting with eyes-closed condition. Their EEG signals were analyzed by time durations and transformed into correlation patterns. The results showed that subjects' EEG correlation patterns during hypothesis-generating were significantly different among individuals. In addition, the EEG correlation patterns were decreased during hypothesis-generating thinking. Furthermore, subject's EEG correlation showed a fluctuationpattern through-out hypothesis-generating, which is presumably caused by the difference of subjects' thinking activities in hypothesis-generating. This study also suggests a possibility that student's scientific thinking ability and the difficulty of scientific knowledge generating may be measured by the analysis of subject's EEG correlation pattern of the prefrontal lobes.

Key words: hypothesis-generating, EEGcorrelation, scientific knowledge generation, undergraduate student, prefrontal lobes

Ⅰ. Introduction

Hypothesis is defined as a single proposition proposed as a possible explanation for the occurrence of some observed phenomena (Barnhart, 1953). Science educators know well that scientific thinking primarily involves generating as well as testing hypotheses. Specifically, hypothesis-generating has been regarded as one of the core reasoning processes in creative thinking and scientific discovery (Klahr & Dunbar, 1988; Kuhn *et al.*, 1988; Lawson, 1995; Kwon *et al.*, 2000; Kwon *et al.*, 2003).

How does the reasoner generate hypothesis? How does the brain work in hypothesis-generating? Cognitive psychologists have explained that the process of hypothesis-generating is an interactive procedure between declarative knowledge and procedural knowledge in the working memory of the brain (Anderson, 1995; Gagne *et al.*, 1997; Solso, 2001). Furthermore,

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they have suggested that the working memory is a necessity for performing a wide range of cognitive tasks including comprehension, learning, and reasoning (Baddeley, 1986; Jonhnstone *et al.*, 1993).

Many experiments have shown that the prefrontal lobes are associated with working memory for problem-solving and reasoning (Milner, 1963, 1964; Fuster, 1973; Lawson, 1993; Robert & Pennington, 1996; Hur *et al.*, 1997 Bear *et al.*, 2001). For example, Milner (1963, 1964) investigated prefrontal patient's inhibiting of perseverative responses. Milner used the Wisconsin Card-Sorting Test that brings out the problems associated with the prefrontal cortex. People with prefrontal lesions had a great difficulty on this task when the sorting category was changed. In addition, Lawson (1993) also found that children's failure to successfully perform on scientific tasks was linked to insufficient operation of the frontal lobes. Therefore, these evidences suggest that the prefrontal lobes may play a crucial role in the performance of higher cognitive activities. Also, a recent clinical study found that the performing of scientific reasoning tasks was significantly involved in functions of the prefrontal lobes (Hur *et al.*, 1997). The study specifically investigated the relationship between prefrontal lobe damage and scientific reasoning ability. The result showed that a prefrontal lesion patient had severely deficient performances on conservation, proportional, combinatorial, probabilistic, and correlational reasoning, as well as control of variable tasks.

Although these previous studies have provided plenty of knowledge about the relationship between scientific reasoning and the brain function, the studies were investigated based on the result of cognitive-psychological experiments which used indirect study methods to examine the function of the prefrontal lobes. However, recent brain imaging technology (such as CT scan, PET, MRI, fMRI, and EEG) has enabled us to understand directly the function of the living brain. These brain imaging methods help us to analyze the relationships between specific areas of the brain and what function they serve. Particularly, electroencephalogram (EEG) is a classical method of the recording of the brain rhythms and is essential for studying various functions of the brain (Kolb & Whishaw, 1996).

EEG rhythms are generated by the synchronization of a lot of neurons. The activity of a large set of neurons produces synchronized oscillations in one of two fundamental ways: (1) They may all take their cues from a central clock, or pacemaker or (2) they may share or distribute the timing function among themselves by exciting or inhibiting one another. Many studies using human EEG signals have shown that EEG synchronization is indexed by coherence or correlation among the EEGs of scalp sites depended on tasks, thinking, and inter-individual differences (Gasser *et al.*, 1983; Klimesch *et al.*, 1996; Mima *et al.*, 2001; Niedermeyer & Lopes, 1999).

According to the above discussions, many studies suggest that the prefrontal lobes play an important role in performance of scientific thinking tasks, and the correlation of the EEG depended on task and inter-individual differences. Therefore, we predicted that the EEG correlation pattern of the prefrontal lobes is dependent on the inter-individual difference among subjects' brain functions and hypothesis-generating tasks. To test this notion, we recorded the EEG signals on the prefrontal scalp sites (Fp1, Fp2, F3, F4, Fz, F7, andF8) during resting and hypothesis-generating with eyes-closed condition, and analyzed the correlation pattern of the EEG signals.

Ⅱ. Methods

1. Subjects

Four male and 6 female healthy undergraduate volunteers participated in measuring EEG signals during resting and hypothesis-generating in this study. All subjects were right handed with no prior history of nervous or psychiatric disorders. EEG data from 2 subjects were discarded because they said they did not generate hypothesis during the recording of the EEG signals in the interview. Mean age of the remaining 8 subjects was 21.3 years (SD = 0.6).

2. Procedure and materials

This study consisted of three data collection sessions EEG baseline-recording, EEG task-recording, and interviewing sessions. In baseline-recording, subject' s EEG signals were recorded for 30 seconds during silent status with eyes-closed condition. The baseline-recording was followed by the EEG-recording of the hypothesis-generating task. Finally, the subjects were asked to tell about the hypotheses that they generated on the task.

Hypothesis-generating task was one involving a ping-pong ball. Subjects were asked to generate possible explanations for the observed phenomena in the ping-pong ball task. In the task, the administrator placed a ping-pong ball in the large open end of the funnel and then blew very hard into the narrow end. What happened was the ball did not go flying. Then the subjects were asked to generate possible hypothesis for the observed phenomenon of why the ball did not go flying.

3. EEG recording and analysis

Subject' s EEG signals were recorded using the E-Series EEG 32 system (Compumedics Neuro Science Pty Ltd., Australia). Recordings were made from 7 scalp sites of prefrontal lobes: frontal pole (Fp1, Fp2), medial frontal (F3, F4, Fz), and lateral frontal (F7, F8). All electrode sites were referenced to Cz. The EEG signals were recorded using electrodes in the 10/20 international system pattern (Jasper, 1958). The electrodes were placed on the subject' s head withconductive gel provided by the electrode manufacturer. Electrode impedances were measured and accepted if they were below 10 K ohms. The electrical activity from each lead was band-passed from 0.1 to 70 Hz. Activity for each lead was displayed on the monitor of a 100 MHz acquisition computer. The EEG signals were digitized online at 256 samples per second for each channel so that the data were not affected by aliasing. The raw data were stored for later analyses.

The baseline EEG signals were recorded for 30 seconds during silent status with eye-closed. During the EEG recording, the subjects were asked to have minimal eye movements and gross motor movements. The baseline-recording was followed by the EEG-recording of the hypothesis-generating task.

The EEG data were transformed and analyzed using Complexity ver. 2.0 software developed by LAXTHA Inc. First, artifacts associated with gross motor movements such as eye movement, swallowing, and hyperventilation were removed. The data then were analyzed with a fast Fourier transform (FFT) using Pearson' s all cross correlation. This analysis produced 49 correlation coefficients. Among these, 21 correlation coefficients produced by a combination of 7 scalp sites were averaged. The average of 21 correlation coefficients of the EEG signals on the prefrontal lobes was named as the correlation value.

Correlation values were analyzed by the Kruskal-Wallis Test and Mann-Whitney U Test with measure factors for subjects and the task. To analyze mean differences between correlation values of the task, mean correlation values were calculated from EEG recording of early 10 seconds and 5 sections of total duration.

Ⅲ. Results and Discussion

1. Subjects' EEG signals and correlation values

Subjects' EEG signals were recorded during resting and performing the task of hypothesis-generating. A pattern of irregular vibration was shown in correlation values of subject's EEG signal (Fig. 1). According to Mima *et al.* (2001), EEG synchronization indexed by correlation among EEG signals of scalp sites is dependent on thinking or cognitive activity of the human brain. Therefore, the irregular vibration of correlation values shown in EEG data analysis is presumably caused by the variation of thinking activity for generating hypotheses.

Each subject's mean score of correlation values which were recorded during resting and performing the task of hypothesis-generating is summarized in Table 1. As shown in the Table 1, the mean correlation values are 0.78 (SD = 0.12) for the rest and 0.69 (SD = 0.11) for the performing hypothesis-generating task. The mean scores of subjects' correlation values on the each task were significantly different in the Kruska-Wallis Tests ($p < 0.01$). The results of these analyses were $x^2 = 105.35$ ($p < 0.01$) for therest and $x^2 = 80.52$ ($p < 0.01$) for the HG, respectively.

These results indicate that there are differences among the mean scores of subjects' correlation values of the resting and the performing of hypothesis-generating tasks. These results are in agreement with studies on the inter-individual differences among the data of the waking normal subjects' EEG rhythms (Gasser *et al.*, 1983; Klimesch *et al.*, 1996).

2. EEG correlation values in the earlier 10 seconds

This study also analyzed the difference of EEG correlation values between the resting and the performing hypothesis-generating task in the earlier 10 seconds and the 5 sections. Vibration of the mean scores of EEG correlation values in the earlier 10 seconds was shown in Fig. 2. Differences among the mean EEG correlation values among the earlier 10 seconds were not statistically significant in the Kruska-Wallis Tests. The results of these analyses were $x^2 = 2.29$ ($p > 0.05$) for the resting and $x^2 = 3.54$ ($p > 0.05$) for the performing hypothesis-generating task.

However, subjects' mean correlation values by task were significantly different in the earlier 10 seconds, which is summarized in Table 2. As shown in the Table 2, the mean scores of EEG correlation values during mental-relaxing and generating hypothesis were 0.78 (SD = 0.11) and 0.69 (SD = 0.15), respectively. The difference of the mean correlation values between tasks was statistically significant in the Mann-Whitney U Test ($U = 2136.00$, $p < 0.05$).

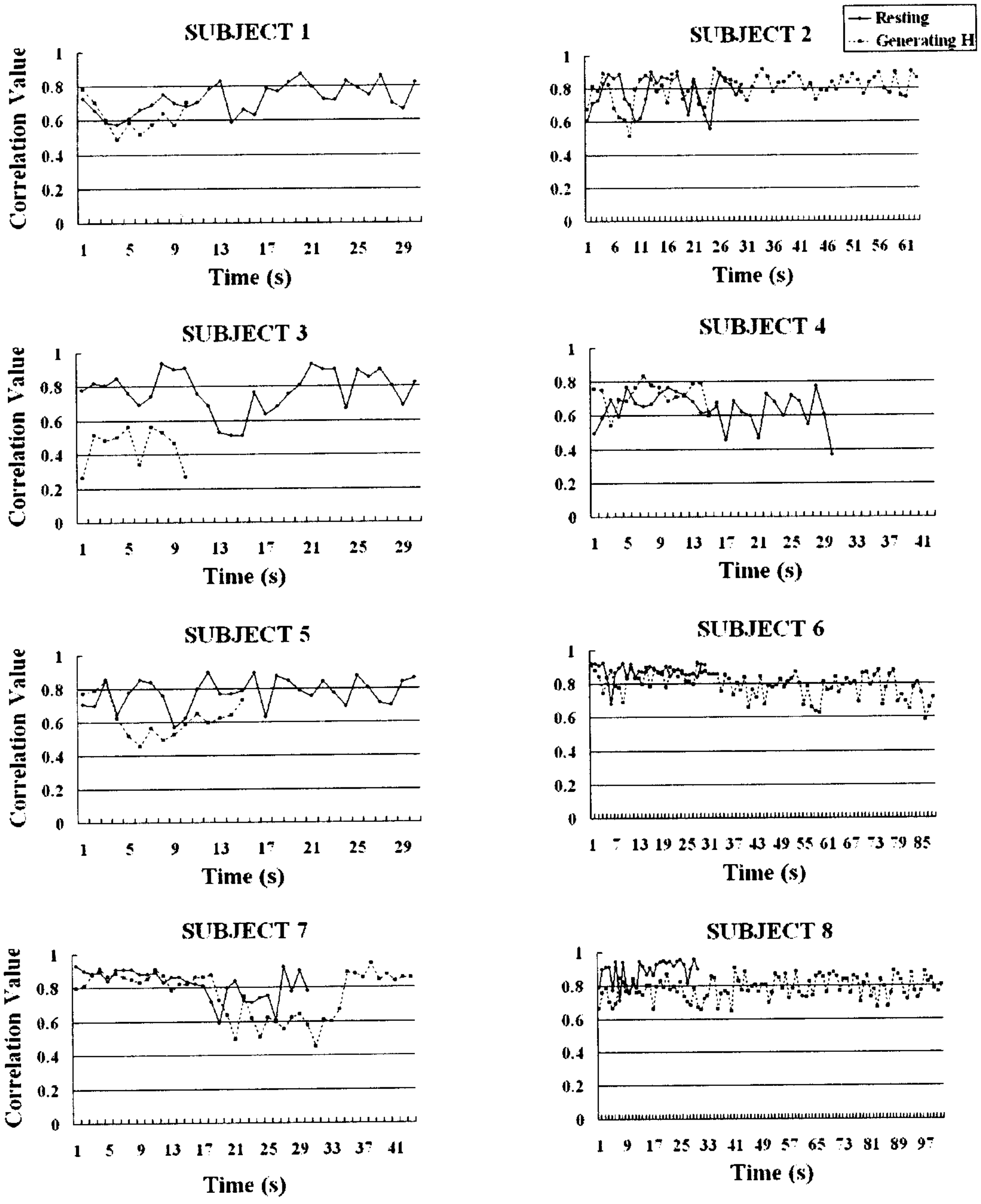

Fig. 1. EEG correlation values during subjects' performing hypothesis-generating task and resting

Table 1. Mean scores of subjects' EEG correlation values

Task A	M	SD	B		C		E		G		H		I		J		Total	
Task	0.72	0.08	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Rest	0.61	0.09	0.77	0.10	0.77	0.12	0.64	0.10	0.77	0.09	0.87	0.05	0.82	0.09	0.88	0.07	0.78	0.12
HG			0.81	0.08	0.44	0.12	0.72	0.08	0.63	0.12	0.80	0.08	0.76	0.14	0.78	0.06	0.69	0.11

* HG : Hypothesis-generating

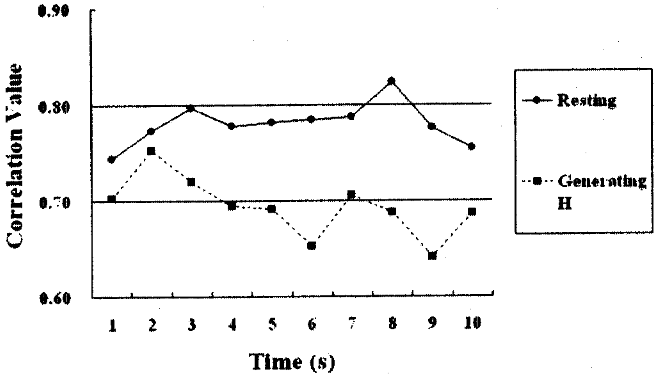

Fig. 2. EEG correlation values by task in the earlier 10 seconds

Table 2. Mean scores of EEG correlation values by task in the earlier 10 seconds

Task	N	Mean	SD	U
Rest	80	0.78	0.11	2136.00*
HG	80	0.69	0.15	

* p 〈 0.05

These results showed that the mean score of EEG correlation values on the hypothesis-generating taskwas significantly lower than the mental-relaxing. The results suggest that EEG synchronization indexed by correlation values among the EEG rhythms of scalp sites depends on the difficulty of task. Recent studies have also suggested a possibility that cognitive activities may be indexed by EEG synchronization (Bear *et al.*, 2001; Mima *et al.*, 2001).

3. EEG correlation values in the 5 sections

Vibration of the mean scores of EEG correlation values is shown in Fig. 3. Differences of the mean correlation values among sections were not statistically significant in the Kruska-Wallis Tests. The results of these analyses were x^2 = 0.25 (p 〉 0.05) for the resting and x^2 = 1.49 (p 〉 0.05) for the performing hypothesis-generating task..

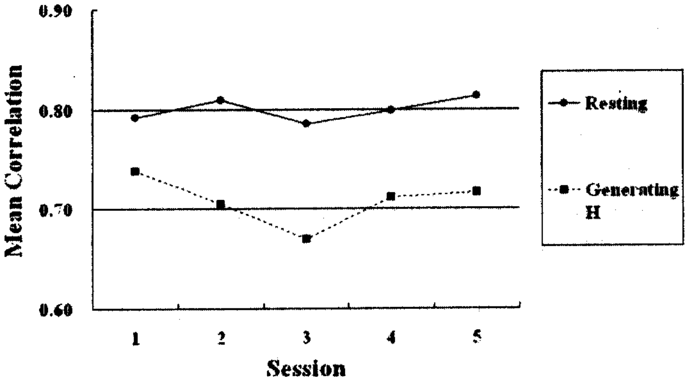

Fig. 3. EEG correlation values by task in the 5 sections

However, subjects' mean correlation values by task in the 5 sections were significantly different, which is summarized in Table 3. As shown the Table 3, the mean scores of EEG correlation values during mental-relaxing and generating hypothesis were 0.80 (SD = 0.09) and 0.71 (SD = 0.14), respectively. The difference of the mean correlation values between tasks was statistically significant in the Mann-Whitney U Test (U = 468.00, $p < 0.05$).

Table 3. Mean scores of EEG correlation values by task in the 5 sections

Task	N	Mean	SD	U
Rest	40	0.80	0.09	468.00*
HG	40	0.71	0.14	

* $p < 0.05$

As shown in the previous results, these results also showed that the mean score of EEG correlation values on the hypothesis-generating task was significantly lower than the resting. These results also suggest that EEG synchronization indexed by correlation values among the EEG rhythms of scalp sites depends on the difficulty of task.

Ⅳ. Conclusion and Implication

The results of this study have shown the statistically significant differences among the mean scores of subjects' EEG correlation values on the cognitive task ($p < 0.05$). Therefore, it is concluded that EEG signals indexed by EEG correlation values of the prefrontal lobes are significantly different among individuals in performing the task of generating scientific-hypothesis. This is in agreement with studies on the inter-individual differences of the EEG data in thewaking normal subjects (Gasser *et al.*, 1983; Klimesch *et al.*, 1996). In addition, this conclusion suggests that one's scientific thinking ability, including hypothesis-generating ability is presumably measured by the analysis of the EEG correlation values of the human brain.

The mean difference score on the resting task was significantly higher than the hypothesis-generating task in the correlation analysis of EEG signals in both the earlier 10 seconds and the 5 sections ($p < 0.05$). Therefore, it is concluded that the EEG correlation values of the prefrontal lobes are decreased in the task of scientific thinking. This is in agreement with studies on the correlation among EEG rhythms of scalp sites on tasks (Bear *et al.*, 2001 Mima *et al.*, 2001). This conclusion suggests that the task difficulty in scientific knowledge-generating is presumably indexed by the analysis of the EEG correlation values of the human brain.

The results of this study have shown a significant mean difference of EEG signals on the prefrontal lobes among subjects ($p < 0.05$). The results have also shown a significant difference of EEG correlation values between tasks, such as the rest and the hypothesis-generating ($p <$ 0..05). Therefore, it is concluded that subject's thinking activities for generating hypotheses are presumably involved in the activities of the prefrontal lobes indexed by EEG correlation values. Furthermore, the present study has provided supporting evidence for the notion that the prefrontal lobes may play an important role in hypothesis-generating (Milner, 1963, 1964; Fuster, 1973; Lawson, 1993; Robert & Pennington, 1996; Hur *et al.*, 1997; Bear *et al.*, 2001). This conclusion suggests that a developmental degree of the prefrontal lobes as well as the ability of hypothesis generation may be measured by the analysis of EEG correlation values of the prefrontal lobes.

Because EEG synchronization indexed by correlation among EEG rhythms of scalp sites depends on task variation of thinking (Defebvre et al., 1996; Niedermeyer & Lopes, 1999; Mima et al., 2001), it may alsobe concluded that the vibration of EEG correlation values of the prefrontal lobes is caused by the variation of thinking during generatinghypotheses. Furthermore, the conclusion suggests a possibility that the intra-individual variation of thinking is probably detected by the analysis of EEG correlation of the human brain.

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