

*Full Length Research paper*

# Patterns of electroencephalography (EEG) change against stress through noise and memorization test

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This study aims to investigate the appearance of brainwaves due to mental stress caused by memory recall and mental calculation, and physical stress caused by noises. We obtained Electroencephalography (EEG) data from 34 healthy subjects while they were at memory test interrupted by noises. Noise was accompanied by instability as it significantly decreased the relative power of the alpha wave of the left parietal lobe as compared to the rest state. In the word or picture memory recall, judging from the significant facts at the occipital and parietal lobes, the relative power of the alpha wave was more decreased, while the relative power of the theta wave was more increased at the occipital and parietal lobes; more so, the relative power of theta was more increased and the relative power of alpha was more decreased when solving the problems than when the problems were given only. Memorizing the process of words and pictures could also be considered as a stress factor like noises. When carrying out the mental calculation, the significant decrease of the relative power of the alpha wave at the occipital and parietal lobes showed instability during problem solving when compared to the rest state. This implies that mental calculation can also be considered as a stress factor. From the point that right-biased alpha wave was analyzed as significantly high in noises that are sometimes generated during the mental calculating process, it is possible to consider asymmetrical interpretation. As a result, noises (a physical stress factor) and memory recall (a mental stress factor) showed reduction of relative power of Alpha wave in the parietal and occipital lobes, and in case of the mental stress factor, even an increase of the relative power of theta wave was observed. Therefore, the appearance of brainwaves due to stresses is used as data to investigate mental activities.

**Key words:** Stress, noise, memory, electroencephalogram, power.

## INTRODUCTION

There have been quite a few studies on the relationship between stress and the alpha wave of electroencephalogram (EEG). The International Federation of Societies for Electroencephalography and Clinical Neurophysiology (IFSECN) proposed the following definition of alpha rhythm. Rhythm at 8-13Hz occurring during wakefulness over the posterior regions of the head, generally with higher voltage over the occipital areas. Best seen with eyes closed and under conditions of physical relaxation and relative mental

inactivity (Ernst and Lopes da Silva, 2005).] For example, cortical inactivation was implicated with an increase in the alpha wave and brain activation was involved in an increase in the beta wave. Increased alpha activity (8-12Hz on the EEG frequency band) was shown to be an indication of brain inactivity, while decreased in alpha activity was an indication of greater brain activity (Niemic, 2002). It is shown by Kimura Mahito that the amplitude of the slow ALPHA amplitude increased just after the stress task, which may indicate cortical deactivation (Kimura et al, 2001). The sensitivity of high alpha to contingent stress was investigated by manipulating conditions known to influence stress, such as the distribution, predictability, and controllability of stressful stimuli, and number of tasks performed (Paul, 1987). Employing a discriminant-analysis

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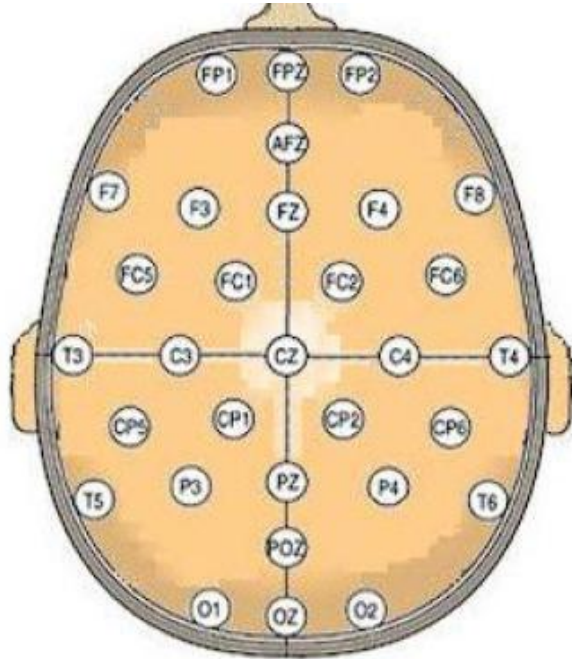


Figure 1. 10-20 System of 32-Channel.

procedure applied to spectral parameters, it proved possible to separate subjectively stressful from non-stressful verbal stimuli, and to determine distinctive EEG responses to verbal stimuli of similar stress value differing only in semantic content (Rakesh, 2007). The mechanism mediating increases in psychological stress, relatively greater right frontal activity, and increases in negative health from naturally occurring stressors is in need of further investigation (Richard et al. 2007).

The findings from study by Jim Lagopoulos suggested that nondirective meditation techniques alter theta and alpha EEG patterns significantly more than regular relaxation (Jim et al., 2009). Moreover, power spectrum analysis showed an increase of 0.25–4.0 Hz in all experimental manipulations, whereas the 4.25–8.0 Hz increase occurred only in the situation of forced wakefulness plus stress (Jim et al., 2009). In addition, non-linear analysis, based on the theory of deterministic chaos, revealed higher and more widespread EEG complexity in the patients compared to the healthy controls only during the recall of the personal pain scene (Werner et al., 1997).

We could confirm part of the human physiological response from EEG. For example, the change of EEG of the specific frequency band in the emotion of fear state, reaction to noise, the memorizing ability were observed, which could be regarded as implying that the interface between a man and external device is possible.

In other words, we expected the influence of stress during memory recall and mental calculation in the sense

that the degree of stress can be known from EEG and checked the reaction to stress from EEG in general by measuring the stress level.

## MATERIALS AND METHODS

### Participants

Thirty four normal subjects aged ranging from 20 to 70 participated in this study with the gender ratio of around 50:50 between male and female. People with low cognitive ability were excluded in the study. For the exclusion criteria, the Korean Mini-Mental State Examination (K-MMSE), a well-known examination for overall cognitive function, was used to exclude those who received the scores less than 24 points out of 30.

### Apparatus and materials

The EEG data were obtained using the 32-channel EEG system (LAXTHA LXE3232-RF). The test had been conducted by considering noise as the major factor of stress and regarding the problem presentation or explanation for answers as one of the stress factors. The test was composed of number memorization, word memorization, picture memorization and mental calculation sequentially for total 19 min and 30 s. Number memorization was composed of five problems (10 s for each problem) and corresponding answers (10 s for each problem), while the rest section of 60 s and three noises (20 s for each noise) was inserted in-between. Word memorization was also composed of five problems (10 s for each problem) and corresponding answers (10 s for each problem), while the rest section of 60 s and four noises (20 s for each noise) was inserted in-between. Picture memorization was composed of five problems (10 s for each problem) and corresponding answers (10 s for each problem), while three noises (20 s for each noise) were inserted in between the problems and the final rest section of 60 s. Finally, the mental calculation was composed of fourteen problems (10 s for each problem) and five noises (10 or 20 s for each noise) inserted in-between the problems.

### Procedures

In the beginning of the experiment, the subjects signed an informed consent and filled out some forms including their demographic information (e.g., age, years of education, handedness, etc.) and medical conditions (medical history, medication, caffeine intake, smoking, depression etc.). The experiment was done as follows.

The EEG was measured at 256Hz sampling rate by placing it on a 10-20 system with a total of 32 channels (Figure 1). After the measurement, the subjects underwent a stress scale survey.

The data were processed as follows. The EEG which went through the 4Hz high-pass filtering process was used in the relative power. It was necessary to regard the EEG under 4Hz as the noise and remove it during the analysis. Therefore with relative power as a denominator, waves under 4Hz, or delta was eliminated. Each of the theta, alpha, beta, gamma waves was obtained by using band-pass filter, the waves were analyzed by relative power. The relative power was redefined as follows.

$$\text{Relative power of alpha wave} = \frac{\text{Al}}{\text{Th} + \text{Al} + \text{Be} + \text{Ga}}$$

$$\text{Relative power of beta wave} = \frac{\text{Be}}{\text{Th} + \text{Al} + \text{Be} + \text{Ga}}$$

**Table 1.** Paired t-tests of noise state and rest state in the tests of number memorization, word memorization, picture memorization and mental calculation.

Variable	Method	Difference	p Value
P3, Pz, CP1, CP5, T5	Alpha	Number_Noise < Number_Rest	.01
		Word_Noise < Word_Rest	
		Picture_Noise < Picture_Rest	

Number\_ Noise represents the five noises of the number memorization; Number\_Rest represents the rest of one minute of the number memorization; Word\_ Noise represents the five noises of the word memorization; Word\_Rest represents the rest of one minute of the word memorization; Picture\_ Noise represents the five noises of the picture memorization; Picture\_Rest represents the rest of one minute of the picture memorization.

$$\text{Relative power of gamma wave} = \frac{\text{Ga}}{\text{Th} + \text{Al} + \text{Be} + \text{Ga}}$$

Where,

- Th=Absolute power of theta wave (4~8Hz)
- Al= Absolute power of alpha wave (8~13Hz)
- Be= Absolute power of beta wave (13~30Hz)
- Ga=Absolute power of gamma wave (30~50Hz)

In general, the theta wave represents meditation, improvement of activity, enhancement of memorization and reduction of stress while the alpha wave represents stability state, the beta wave immersion degree, the gamma wave tension and active high-degree cognition process.

Number memorization, picture memorization and word memorization were compared and analyzed respectively for the corresponding rest section, and mental calculation was compared and analyzed with the average of data of the aforementioned three rest sections.

For reference, the areas of frontal lobe (Fp1, Fpz, Fp2, aFz, F3, F4, F7, F8, Fz, FC1, FC2, FC6 and FC5) which are affected a lot by noise were excluded during analysis.

## RESULTS

We could analyze EEG against the number stimulus, word stimulus and picture stimulus by memorization, metal calculation process and noise as the stress factor by the relative power and its degree of asymmetric deviation. The paired t-test with the rest state was executed by having thirty four subjects as the sample group, and the degree of the activation was evaluated by checking the case that showed the change only in either of the left or right side only when the asymmetry was shown for the specific EEG of the left and right electrode positions.

### Relative power of EEG

The results of the EEG relative power obtained from this study are all significant, and the consistent results of the theta, alpha and gamma waves of the posterior region of brain against the stress stimuli of noise, problem

presentation and explanation of answers were observed.

### Noise

As shown in Table 1, the relative power of the alpha wave was significantly decreased around the parietal and left central-parietal lobes as compared to the rest duration when noise was applied. In other words, we could see that noise decreases the alpha wave which represented the stability state and considered noise as one of the factors of stress from this fact (Figure 2).

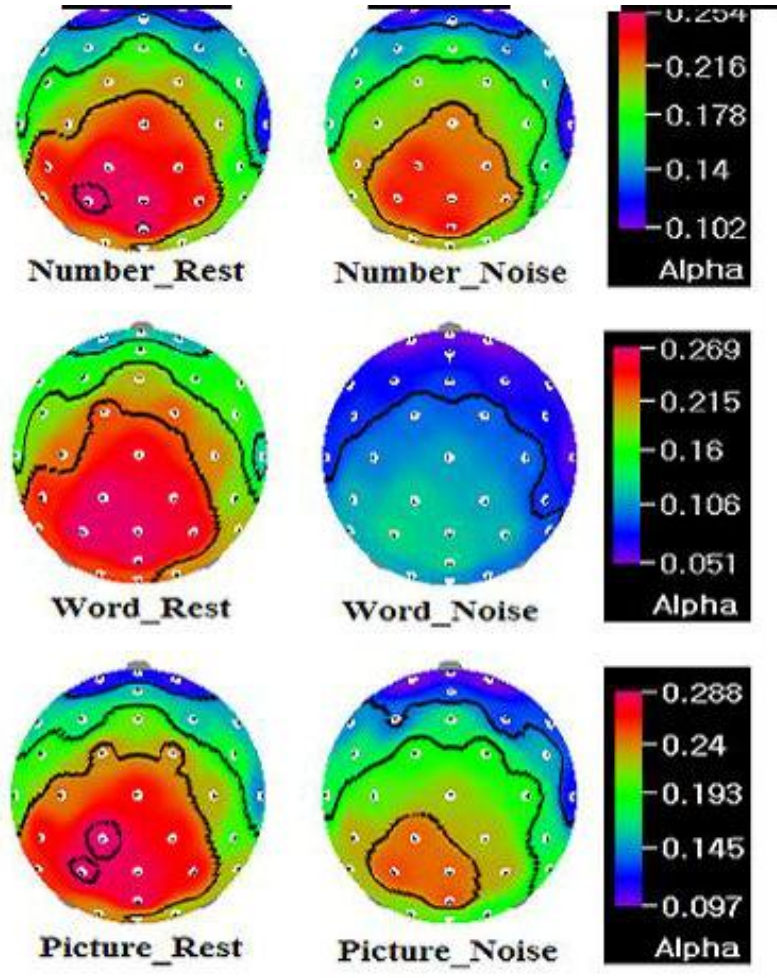
### Number memorization

As shown in Table 2, in case of word memorization, the relative power of the theta wave around the parietal, central-parietal and central lobe was significantly higher in the problem solving than the problem presentation, and the relative power of the alpha wave around the occipital, occipital-parietal and parietal lobe was significantly lower. This represented that the problem solving process was more instable than the stimulated problem presentation and stress is increased (Figure 3).

### Picture memorization

As shown in Table 3, in case of picture memorization as well as the word memorization, the relative power of the alpha wave around the occipital, occipital-parietal and parietal lobe was significantly lower in the problem solving than the problem presentation. This represented that the problem solving process was more unstable than the stimulated problem presentation (Figure 4).

In addition, the fact that the relative power of the theta wave of each of problem presentation and the problem solving process is lower at the left occipital and left parietal in the problem presentation and significantly lower at the occipital, occipital-parietal and parietal in the problem solving as compared to the rest state was related with the increase of stress, and the decrease of



**Figure 2.** Brain-mapping of average relative power of alpha wave in noise state and rest state.

**Table 2.** Paired t-tests of problem presentation and explanation of problems in the memory recall of words.

Variable	Method	Difference	p Value
T6, POz, C3, P4, CP2, CP5, CP6, Pz, P3, CP1, Cz, C4,	Theta	Word_Problem < Word_Answer	<.01
Oz, O1, Pz, CP2, P3, P4, POz	Alpha	Word_Problem > Word_Answer	<.01

Word\_Problem represents the presentation of five problems of the word memorization. Word\_Answer represents the solution of five problems of the word memorization.

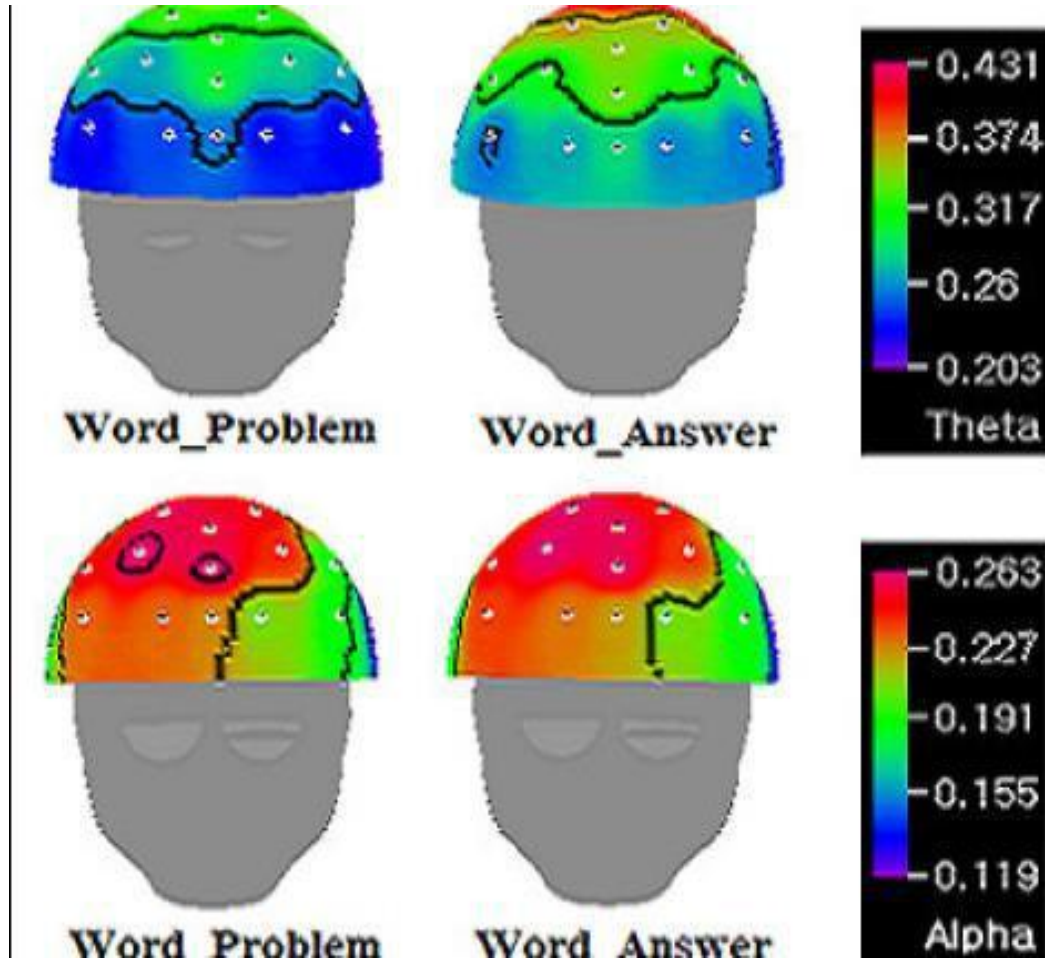
relative power of the alpha wave at the occipital, occipital-parietal, and parietal was related with instability (Figure 4)

### **Mental calculation**

In addition, as for the mental calculation problem solving, the high-degree cognition can be seen by the significant

increase of the relative power of the gamma wave of the occipital and occipital-parietal lobe.

As shown in Table 4, in case of mental calculation, the relative power of the alpha wave around the occipital, occipital-parietal, and parietal lobe was significantly lower in the problem presentation as compared to the rest state, and the relative power of the gamma wave around the occipital and occipital-parietal lobe was significantly



**Figure 3.** Brain-mapping of average relative power of theta and alpha waves in the memory recall of words

**Table 3.** Paired t-tests of problem presentation and rest state, explanation of problems and rest state, and problem presentation and explanation of problems in the memory recall of pictures.

Variable	Method	Difference	p Value
O2, P4, POz, P3, CP5, T3, C3	Theta	Picture_Problem > Picture_Rest	<.01
Pz, C4, CP1,T6, Oz, Cz, C3, CP5,T3, O1, O2, POz, P3, P4	Theta	Picture_Answer > Picture_Rest	<.01
Oz, O2, POz, P3, CP1, T5,P4	Alpha	Picture_Answer < Picture_Rest	<.01
Oz, O1, O2, P3, CP2, POz	Alpha	Picture_Problem > Picture_Answer	<.01

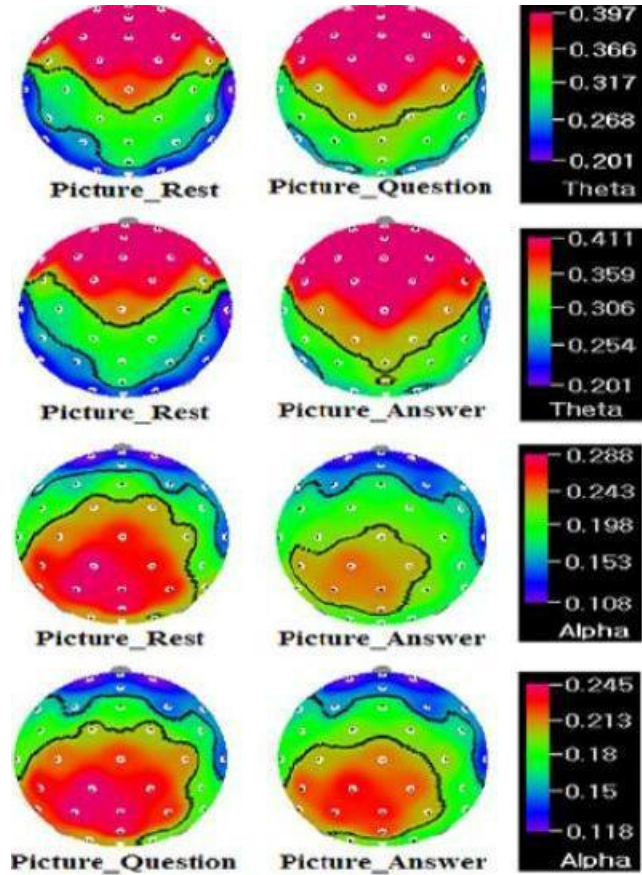
Picture\_Problem is regarding the presentation of five (5) problems of the picture memorization; Picture\_Answer is regarding the solution of five (5) problems of the picture memorization.

higher. From this, we could see the stimulus of mental calculation represented instability, tension and high-degree cognition (Figure 5).

#### Asymmetric deviation

Table 5 showed the deviation of noise, that is, only one

side of the left or right state increased or decreased in the left-right asymmetric case against the relative power of four EEGs in the 90% confidence interval as a result of the paired-test of each stress and relevant rest section. If we took noise as one of the factors of stress, we could identify the measure of EEG against noise, and by comparing this with EEG of the various kinds (numbers,



**Figure 4.** Brain-mapping of average relative power of theta and alpha waves in the memory recall of pictures.

**Table 4.** Paired t-tests of the mental calculation process and rest state in the mental calculation test.

Variable	Method	Difference	p Value
Oz , POz, P3, CP1, T6, O2, P4	Alpha	Mental Calculation_Problem < _ Rest	<.001
O1, POz, O2, Oz	Gamma	Mental Calculation_Problem > _ Rest	<.01

\_ Rest is the average of each rest of the three (3) rests, that is, word, number and picture memorization; Mental Calculation\_Problem is regarding the presentation of five (5) problems of the mental calculation.

words, pictures) problem presentation or explanation, create the stress effect for a certain problem presentation and problem solving, and We could judge that the noise applied to the subject, presentation of specific problems and problem solving stimuli increase or decreases the specific EEG of the specific part.

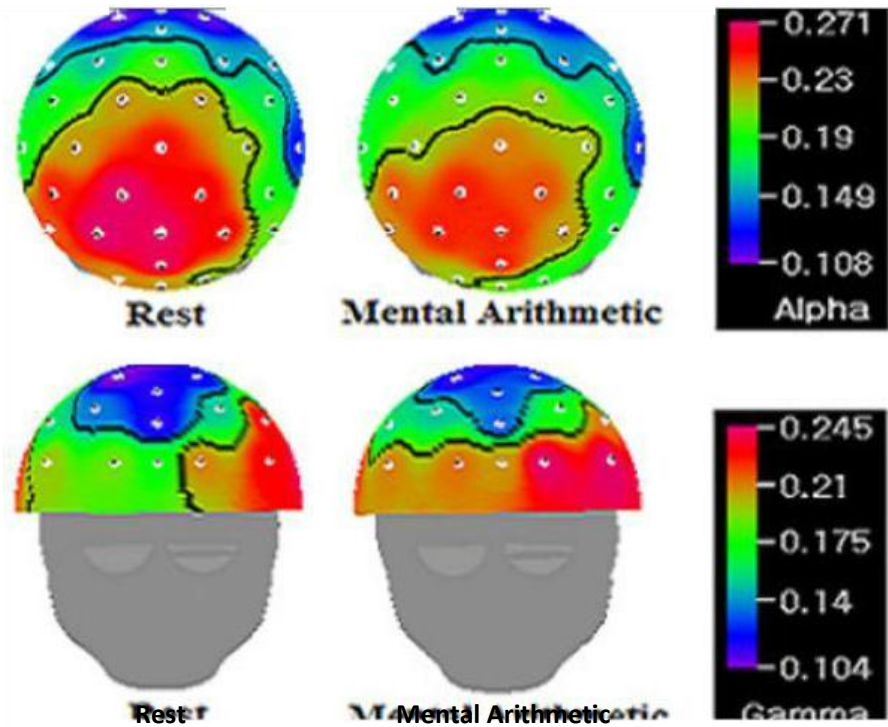
### Noise

When the noise section was compared during mental calculation against the rest section, the relative power of the theta wave against T3 and T4 was significantly asymmetric from side to side ( $p < .0025$ ) and increased only in T4. The relative power of the gamma wave was

asymmetric and decreased only in T4. The relative power of the beta wave was asymmetric from side to side against T5 and T6 and increased only in T5. The relative power of the theta wave was significantly asymmetric from side to side against CP5 and CP6 ( $p < .005$ ) and increased only in CP6 while the relative power of the gamma wave was asymmetric and decreased only in CP6 (Figure 6).

### DISCUSSION

Generally, noise was accompanied by instability as it significantly decreased the relative power of the alpha wave of the left parietal lobe as compared to the rest



**Figure 5.** Brain-mapping of average relative power of alpha and gamma waves in the mental calculation

**Table 5.** Asymmetric deviation of noise state and rest state in the mental calculation test by the paired t-tests against the relative power of each of the theta, alpha, beta and gamma waves.

Variable	Method	Difference	p Value
T3 minus T4	Theta	Mental Calculation_Noise < Mental calculation _ Rest	<.0025*
T4		Mental Calculation_Noise > Mental calculation _ Rest	<.05
CP5 minus CP6		Mental Calculation_Noise < Mental calculation _ Rest	<.005*
CP6		Mental Calculation_Noise > Mental calculation _ Rest	<.05

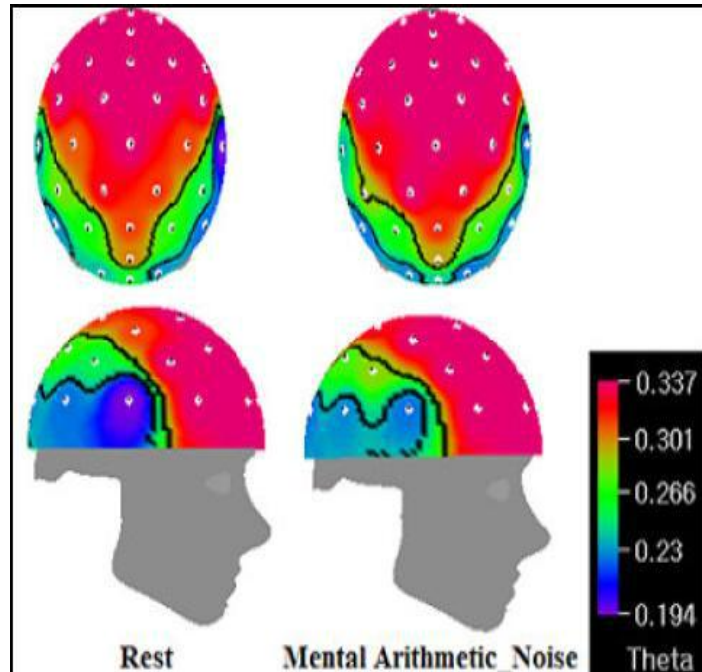
\* Significance level  $p < .01$ ; Mental Calculation\_Noise is regarding the five (5) noises of the mental calculation.

state. And, in the word and picture memory recall, judging from the fact that the relative power of the alpha wave decreased more significantly at the occipital, occipital-parietal and parietal lobe, we could see that it was more instable when solving the problems than when only the problems were given, and additionally, it could be said that more stress occurred when solving the problems of word memory recall than when only the problems were presented as there was significant increase of the relative power of the theta wave at the right central-parietal lobe. As considering only the time when memorizing the pictures, more stress occurred by the significant increase of the relative power of the theta wave at the occipital, occipital-parietal, parietal and central-parietal lobe when both receiving problems and solving them as compared to the rest state. Solving the problems could be said as showing from the significant decrease of the relative power of the alpha wave to instability at the occipital,

occipital-parietal and parietal.

When carrying out the mental calculation, the significant decrease of the relative power of the alpha wave at the occipital, occipital-parietal and parietal lobe showed instability during problem solving when compared to the rest state. As the decrease of the relative power of the alpha wave at the left parietal (CP1, P3) commonly occurred also in the noise and picture problem solving, the mental calculation process, sudden noise and short-term picture memorization could be considered as the factors causing instability. In addition, as for the mental calculation problem solving, the high-degree cognition can be seen by the significant increase of the relative power of the gamma wave of the occipital and occipital-parietal.

These results confirmed to several researches. For example, it is shown by Paul D. Tyson that the dual-task subjects produced less alpha wave. And it is shown by



**Figure 6.** Brain-mapping of asymmetric deviation of noise state and rest state in the mental calculation test against the relative power of the theta wave

(Dimpfel et al, 1993) that concentration performance test effect decreases in power in the alpha range in parietal cortex and enhanced theta power in occipital regions. This inverse proportion between stress and alpha wave in parietal lobe was confirmed in the problem of word and picture memorizations solving than the problem presentation, and in the problem of picture memorizations solving and the mental calculation process than the rest state on this experiment. Moreover the direct proportion between stress and theta wave in occipital lobe was confirmed in the mental calculation process required the high-degree cognition. Memorizing process of words and pictures could be also considered as a stress factor like noises.

In addition, it is noted by Schacter (1997) that increase in theta activity occur in conjunction with several kinds of psychological process. It was underpinned by the increase of the relative power of theta wave in being reminiscent of words and pictures remembered on this experiment in that stress is the physiological response reflecting psychological factors. In particularly, from the point that right-biased alpha wave was analyzed as significantly high about noises sometimes generated during the mental calculating process, it is possible to consider asymmetrical interpretation.

As a result, noises (physical stress factor), and memory recall (a mental stress factor) showed reduction of relative power of alpha wave in the parietal and occipital lobe, and in case of the mental stress factor, even increase of relative power of theta wave was observed.

Therefore, the appearance of brainwaves due to stresses is thought to be used as data to investigate mental activities.

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