Kütahya Dumlupınar University
Institute of Graduate Studies

Journal of Scientific
Reports-A
E-ISSN: 2687-6167
Number 51, December 2022

RESEARCH ARTICLE

EVALUATION of the RELATIONSHIP BETWEEN EEG BAND POWERS and COGNITIVE TASKS

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Receive Date:18.08.2022 *Accepted Date: 02.11.2022*

ABSTRACT

To examine our brain's responses to different cognitive activities, the brain signals of 30 volunteers were evaluated in terms of verbal memory, visual memory, verbal attention, visual attention and mental processing speed cognitive activities by using Electroencephalogram (EEG) signals. The correlation between cognitive activities and EEG signals was analyzed by examining the EEG signals recorded during the resting state of the volunteers and during five different cognitive activities (Öktem Verbal memory test, Wechsler Memory Scale (WMS) visual memory subtest, Digit span test, Corsi block test and Stroop test). The spectral features of four EEG subbands (delta, theta, beta and alpha) were extracted from the EEG signals at rest and from the EEG signals during each cognitive activity using the Welch method. When the extracted features were evaluated statistically using the ANOVA test, it was observed that there were changes in the EEG bands of the volunteers who passed from the resting state to the test state. It was observed that the relative beta values of the volunteers' EEG signals decreased in the Öktem verbal memory processes test and Digit span test, while the relative alpha values decreased during the visual memory, Corsi block and Stroop tests.

Keywords: *ANOVA, Cognitive tasks, EEG band power, Relative alpha, Relative beta.*

1. INTRODUCTION

Although there are older studies on measuring electrical activities in the human brain, Berger's work on measuring the brain's electrical signals in the human skull [1] is accepted as the beginning of EEG studies. EEG signals have a frequency band in the range of 0.5 – 100 Hz in the low-frequency region. However, as a result of research, it has been seen that different brain activities and physical conditions

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affect different subbands in this wide frequency band, and different names have been given to distinguish these subbands from each other. These subbands are called delta (δ), theta (θ), alpha (α), beta (β), and gamma (γ) [2]. These frequency bands are associated with different brain processes [3]–[6].

The spectral power densities of EEG subbands may differ in different task situations. When the studies in the literature were evaluated, it was seen that the EEG signals during mental tasks were evaluated using different experimental paradigms. One of the commonly used mental tasks is the n-back paradigm. The N-back paradigm is widely used in EEG and working memory, fatigue and mental workload studies [7]–[9]. In some of the studies, mental tasks were evaluated with the amplitudes of the EEG subbands. In a study done [10], To observe the difference between short-term memory and working memory, EEG signals were recorded while applying the Corsi block test [11] to 18 healthy young male volunteers, beta and gamma band powers were observed to be lower. It has been seen from the literature that there are changes in different EEG band powers during various tasks. In one of the first studies in which mental arithmetic tasks were applied, it was observed that the theta band strengths increased while the alpha band powers decreased while the volunteers were performing the tasks [12]. In another study on mental arithmetic tasks, it was stated that theta and alpha band strengths changed during number processing tasks [13]. Some recent studies suggest that theta and alpha bands are responsible for mental arithmetic tasks and change during these tasks [14], [15]. Another study examining the difficulty of tasks during mental arithmetic tasks said that theta and alpha bands are associated with numerical task processes [16]. Low beta activity is indicative of successful memory encoding, and decreases in beta power are seen in memory-related tasks [17], [18]. Decreases in alpha and beta powers are seen in cognitive and estimation tasks [19]–[21].

When all these studies were evaluated, it was seen that the verbal, visual or numerical cognition of the volunteers was evaluated by applying one-way tests. In this study, the cognitive activities of volunteers were evaluated with versatile tests and experimental studies. It is presented as a contribution to the literature that the decrease in the relative beta band is associated with verbal and numerical retention and recall tasks, and the decrease in the relative alpha band is associated with cognitive tasks with visual content.

This paper is organized as follows: in the second part of the study, participants, mental tasks, data collection and preprocessing steps are mentioned under the title of materials and methods. In the third part, the evaluation of the results is given. In the fourth chapter, the conclusion sections are presented.

2. MATERIAL and METHOD

2.1. Participants

The 30 volunteers participating in the study are healthy individuals. All volunteers signed an informed consent form. In addition, the ethics committee approval of the study was obtained from the Clinical Research Ethics Committee of Kütahya Health Sciences University.

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2.2. Experimental Paradigm

The EEG signals recorded in this study were evaluated in two parts resting state and cognitive test moments. First, each volunteer's EEG signals at rest were recorded. Then, five different cognitive tests measuring the verbal memory, visual memory, verbal attention, visual attention and reaction time abilities of the volunteers were applied to the volunteers and the EEG signals during the tests were recorded. The experimental paradigm is as given in Figure 1. Tests applied: Öktem verbal memory processes test, WMS-R visual memory subtest, Digit span test, Corsi block test and Stroop test.

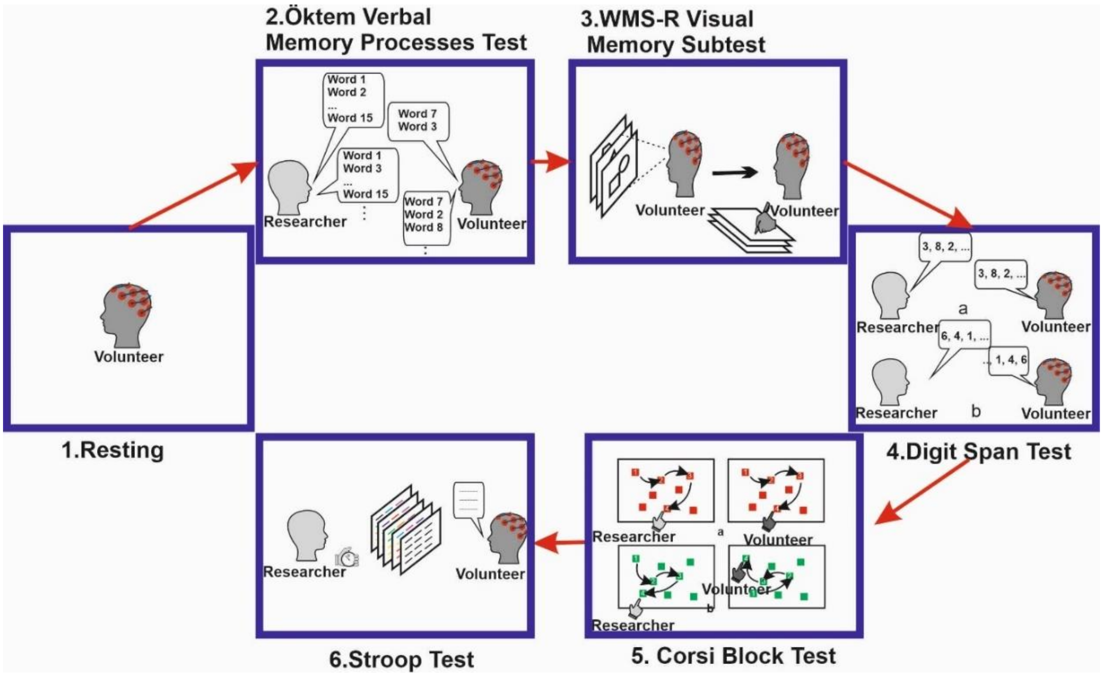

Figure 1. Experimental paradigm.

Resting state: During the resting, the volunteers were given commands such as eye-open, eye-close and eye-open, respectively, and then the EEG signals of the volunteers were recorded while their eyes were open.

Öktem verbal memory processes test: It is a word test that measures the verbal memory and learning abilities of volunteers [22], [23]. Volunteers are asked to repeat the words they have in mind without any order. Each volunteer performed this test in 10 trials.

Wechsler Memory Scale Revised (WMS-R) visual memory subtest: It is a visual memory test that measures the visual memory and learning abilities of volunteers [24]. Three different pictures are shown to the volunteers in sequence for a certain period and after each picture is turned off, the

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volunteers are asked to draw the pictures. This test was repeated 3 times as each volunteer was shown three different pictures.

Digit span test: The test shows the efficiency and capacity of attention and concentration to repeat numbers forward, consisting of two stages. Saying numbers backward is an execution task that depends on working memory [25], [26]. The test consists of repeating the number sequences read to the volunteers in the same order after the researcher and saying the numbers from the end to the beginning, retention numbers. Since there were 9 different number sequences forward and 8 different number sequences backward within the scope of this test, the volunteers performed this test in 9 trials forward and 8 trials backward.

Corsi block test: It is a two-stage visual attention test consisting of touching the squares shown to the volunteers in the same order after the researcher and handling the squares that the researcher touched from the end to the beginning, retention the frames that the researcher touched [11]. The step of touching forward squares of the test is evaluated as visuospatial memory space. Tapping the memorized frames from top to bottom measures working memory capacity. As there were both eight forward patterns and eight backward patterns within the scope of this test, the volunteers followed and applied these patterns in 8 forward trials and 8 backward trials.

Stroop test: During this test, which measures the mental processing speed of the volunteers, the volunteers are asked to quickly read five cards or say the colors of what is written on the cards [27], [28]. Since each volunteer read five different cards, each volunteer applied this test in 5 trials.

2.3. Data Acquisition and Preprocessing

EEG signals of 30 volunteers were recorded with a 16-channel Nihon Kohden EEG device. The device takes 500 samples per second.The block diagram showing the working stages is given in Figure 2. The study consists of the steps of separately collecting EEG data at rest and cognitive test moments, filtering the collected data, extracting spectral features from the data, and comparing the EEG features at rest/test states using statistical analysis.

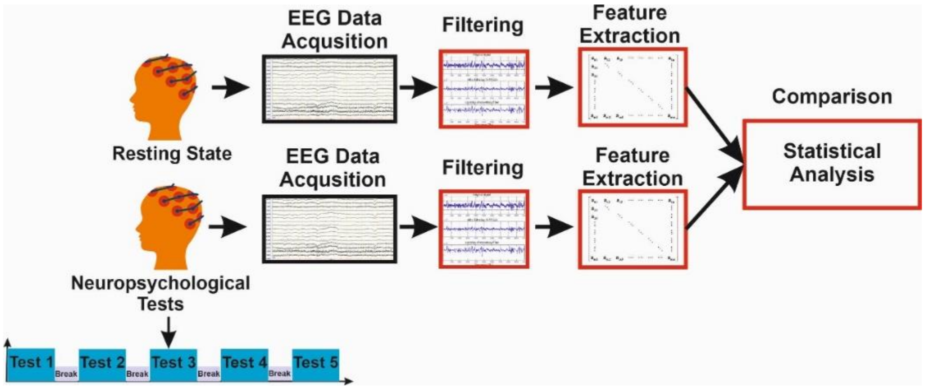

Figure 2. Experimental paradigm.

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The data collection step consists of two parts. In the first part, EEG signals were recorded while the volunteers were at rest and their eyes were open. In the second part, EEG signals were recorded while the volunteers were performing five different cognitive tasks. The application of cognitive tasks to volunteers was explained in the experimental paradigm section. Data were separated according to rest and cognitive test moments. Each EEG data was marked to which state it belongs and these data were separated according to the signs.

In the filtering phase, the independent component analysis (ICA) method [29], [30] and 50 Hz notch filter [31] were applied to EEG data. Thus, the signal was freed from the eye artifacts and 50 Hz mains frequency.

In feature extraction, the spectral features of the EEG subbands were extracted using the Welch [32], [33] method of the EEG signal. Detailed information about the extraction of features was explained in the section extraction of spectral features.
Finally, in the comparison step, the features at rest and cognitive test time were statistically evaluated with the One Way ANOVA test. Here, the most significant features were determined for each test and their status when they passed the test state without resting was evaluated.

2.4. Extraction of Spectral Features
Within the scope of the study, spectral power densities for delta, theta, beta and alpha subbands were extracted from the EEG signals in the resting state and when the volunteers performed cognitive tests, using the Welch method and the relative powers were calculated for each subband. In Eq. 1, the periodograms of the input function particles divided into time slots are calculated with the appropriate window function.

$$P_i(f) = \frac{1}{M}\frac{1}{H}\left[\sum_{n=0}^{M-1} w[n]x_i[n]e^{-j2\pi fn}\right]^2 \tag{1}$$

Shown as $x_i[n]$ in the equation, i. is the periodogram of the piece. w[n] is the selected window function in the equation. M is the length of the particles and should be equal for each. H is the normalized window function and can be calculated in Eq. 2.

$$H = \frac{1}{M}\sum_{n=0}^{M-1} w[n]^2 \tag{2}$$

By taking the average of the periodograms of the obtained particles, the power spectral density is obtained by the Welch method as in Eq. 3.

$$P_{welch}(f) = \frac{1}{S}\sum_{i=1}^{S} P_i(f) \tag{3}$$

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In Eq. 4, the equation for calculating the power spectral densities of each subband with the Welch method is given.

$$(f) = \frac{1}{S}\sum_{i=1}^{S} P_i(f)\ ;\quad f = \begin{cases} 0.4Hz < f < 4Hz & , Delta\ band \\ 4Hz < f < 8Hz & , Theta\ band \\ 8Hz < f < 12Hz & , Alpha\ band \\ 12Hz < f < 30Hz & , Beta\ band \end{cases} \tag{4}$$

In Eq. 5, the equation for the calculation of the relative power spectral densities for each subband with the Welch method is given.

$$\mathrm{P}_{relative} = \frac{P_{subband}}{P_{toplam}} \tag{5}$$

These features were extracted separately from the volunteers' resting state EEG signals and from the EEG signals recorded during the five cognitive tests.

3. EVALUATION of RESULTS

In the evaluation phase, the spectral features of the resting state and the test moment were analyzed with the One Way ANOVA test. F and p values were evaluated for each test and are given in Table 1.

Table 1. F and p-value for each test as a result of the evaluation of the subbands with the ANOVA test to determine the correlation between the resting moment and the test moments from the EEG subbands.

		Öktem-SBST	**WMS-R Visual Memory Sub Test**	**Digit Span Test**	**Corsi Block Test**	**Stroop Test**
Relative Delta	**F**	20.408	1.510	127.948	31.290	36.461
	p	$7x10^{-6}$	$2.19x10^{-1}$	$1.72e^{-28}$	$2.65e^{-8}$	$2.21e^{-9}$
Relative Theta	**F**	0.862	7.061	1.465	2.171	0.471
	p	$3.53x10^{-1}$	$8.01x10^{-3}$	$2.26x10^{-1}$	$1.41x10^{-1}$	$4.93x10^{-1}$
Relative Beta	**F**	**83.854**	7.380	**230.723**	97.307	45.943
	p	$\mathbf{3.06e^{-19}}$	$6.72x10^{-3}$	$\mathbf{1.77e^{-48}}$	$2.91e^{-22}$	$2.11e^{-11}$
Relative Alpha	**F**	7.592	**68.116**	144.916	**125.152**	**75.622**
	p	$5.92x10^{-3}$	$\mathbf{4.97e^{-16}}$	$6.95e^{-32}$	$\mathbf{6.27e^{-28}}$	$\mathbf{1.44e^{-17}}$

When Table 1 was examined, it was seen that the most significant F and p-values obtained as a result of the ANOVA test for the Öktem Verbal memory processes test were in the relative beta feature. As shown in Figure 3, the relative beta value of the volunteers in the resting state was higher than that of the volunteers who performed the Öktem verbal memory processes test. It is known that beta power decreases as the difficulty of the task increases [34]. During the Öktem verbal memory processes test, the volunteers tried to retain and say them by recalling them.

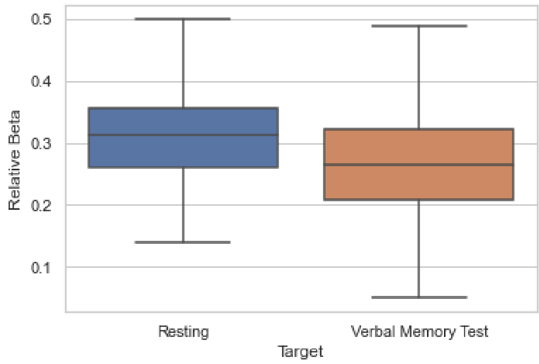

Figure 3. Box plot showing the relative beta subband power of the resting state and Öktem-Verbal Memory Processes Test.

When the ANOVA test results for the WMS-R visual memory subtest were analyzed from Table 1, it was seen that the most significant F and p-values were in the relative alpha feature. As given in Figure 4, the relative alpha value of the volunteers in the resting state was higher than that of the volunteers who performed the WMS-R visual memory subtest. A decrease in alpha band power is observed with an increase in mental workload, especially during visual tasks [35], [36]. In this study, the relative alpha power decreased compared to the resting state during the visual memory task.

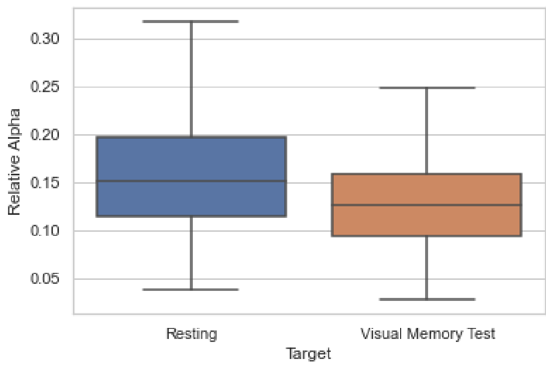

Figure 4. Box plot showing the relative alpha subband powers of the resting state and WMS-R Visual Memory Test.

When the ANOVA test results for the digit span test were analyzed from Table 1, it was seen that the most significant F and p-values obtained were in the relative beta feature. As shown in Figure 5, the volunteers' relative beta value in the resting state was higher than the relative beta value when performing the Digit span test. The volunteers performed retention and recall in the Digit span test, as in the Öktem verbal memory processes test.

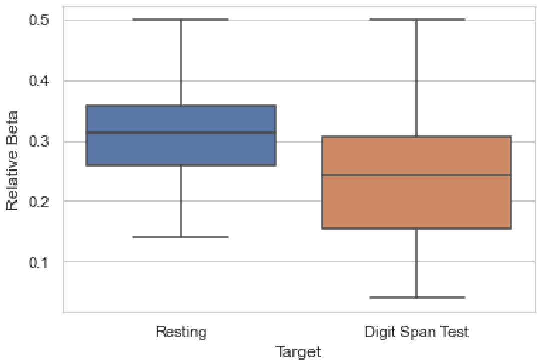

Figure 5. Box plot showing the relative beta subband power of the resting state and Digit Span Test.

During the Corsi block test, the volunteers followed the blocks visually and performed the same procedure. When the ANOVA test results for the Corsi block test were analyzed from Table 1, it was seen that the most significant F and p-values obtained were in the Relative alpha feature. As shown in Figure 4, the relative alpha value of the volunteers in the resting state was higher than that of the volunteers who performed the Corsi block test.

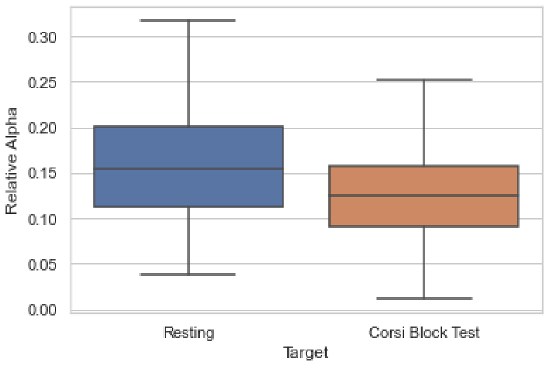

Figure 6. Boxplot showing the relative alpha subband powers of the resting and Corsi Block test.

When the ANOVA test results for the Stroop test were analyzed from Table 1, it was seen that the most significant F and p-values obtained were in the relative alpha feature. As shown in Figure 7, the

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relative alpha value of the volunteers at resting state was higher than that of the volunteers who performed the Stroop test. Changes in the alpha band are associated with attentional processes and inhibition of irrelevant information [37], [38]. In addition, there is a procedure in which visual abilities are measured, as in the Corsi block test and WMS-R Visual Memory subtest.

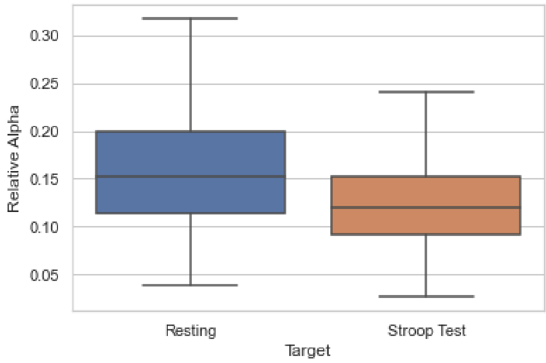

Figure 7. Box plot showing the relative alpha subband power of the resting state and Stroop Test.

4. CONCLUSION

Within the scope of the study, the EEG signals recorded during the resting state of 30 volunteers and while applying five cognitive tests were examined. Signal preprocessing was applied to EEG data. The spectral features of the EEG subbands were extracted from the recorded EEG signals using the Welch method, and these spectral features were evaluated statistically. As a result of the relationship between the cognitive test states and the resting states evaluated with the ANOVA test, the volunteers who switched from the resting state to the cognitive test state made a mental effort and the mental workload of the volunteers increased. The most significant spectral feature for each test was found with the help of ANOVA test. While the Öktem verbal memory processes test and the digit span test included retention and verbal recall tasks only, the relative beta power of the volunteers who performed this test decreased. Volunteers performed tasks with visual content during the WMS-R visual memory test, Corsi block test, and Stroop test, and their relative alpha power decreased compared to the resting state. In this study, it was observed that there were changes in different EEG bands during different cognitive tasks.

In different task situations, the difficulty and duration of the task are the factors affecting the task's success. The limits of the study are limited to the experimental group. In future studies, the experiments can be repeated by increasing the experimental group. In addition, the effects of cognitive tasks on sick individuals can be examined from EEG signals by working on individuals with impaired cognition. Furthermore, standardized different tasks can be determined, the examination can be carried out. System performance can be evaluated with novel performance metrics such as the current polygon area metric.

ACKNOWLEDGEMENT

This study was supported by the Scientific Research Projects of Kütahya Dumlupınar University within the scope of the project numbered 2020/26. Also, it was conducted by researchers at Kütahya Dumlupınar University Neurotechnology Education Application and Research Center.

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