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A. BEHZADNIA,[1] M. GHOSHUNI,[2] and S. A. CHERMAHINI[3]

EEG ACTIVITIES AND THE SUSTAINED ATTENTION PERFORMANCE

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We investigated the relations between EEG activity and sustained attention in humans. A visual version of the conjunctive continuous performance task (CCPT-V) was used as a measure of sustained attention. Twenty university students voluntarily participated in the study; they were divided into two groups, good and weak, according to their results in the CCPT-V. The spectral power of EEG recorded from Fz, Cz, and Pz was analyzed under three conditions (eyes-open, eyes-closed, and CCPT-V) in four frequency ranges, theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz) and gamma (30–60 Hz) in three channels. Results of repeated-measures MANOVA showed the significance of the effects of conditions and channels with respect to the alpha and theta but not to the beta and gamma powers. There was no significant effect of the group, but, when comparing the alpha power under three conditions, the good group showed lower spectral powers. It has been concluded that cerebral neuronal systems producing alpha and theta oscillations play a role in sustained attention, and this can be shown by EEG recording and in the respective test.

Keywords: conjunctive continuous performance task (CCPT), electroencephalography, frequency ranges, sustained attention.

INTRODUCTION

It has been shown in a number of studies that EEG frequency bands (rhythms) can be specifically related to certain brain functions [1-3]. The cognitive performance in humans is a crucially important brain function, which recently is in the scope of intense research applying EEG to explore the respective neuronal mechanisms. Attention is one of the important aspects of cognitive performances. As was revealed, attention is one of the most important cognitive factors playing significant roles in reasoning [4, 5], safe driving [6-8], consciousness [9], memory [10], and so on.

Attention known as concentration and alertness is one of the central aspects of human cognition, and high level of attention facilitates memory processes [11]. Sohlberg and Mateer [12, 13] described five levels, or types, of attention including the following. *Focused attention* is the ability to respond discretely to specific items of information (visual, auditory, or tactile stimuli). *Selective attention* is the ability to select certain factors or stimuli from their multiplicity and to focus on only the one that you want, while avoiding distractions from other external and internal stimuli. *Alternating attention* refers to the ability or capacity for mental flexibility, which allows individuals to shift their focus of attention and to alter it between tasks having different cognitive requirements. *Divided attention* is the highest level of attention, and it refers to the ability to respond to multiple tasks within the same time. Finally, *sustained attention* is the ability to focus on one specific task for a continuous amount of time or to maintain a consistent behavioral response during continuous and repetitive activity without being distracted.

Sustained attention represents higher aspects of attention and cognitive capacity in general [14]. The cognitive construct of sustained attention has been greatly advanced recently. The development and validation of diverse tasks for testing sustained attention supports this claim, which in turn enhance research of the neuronal mechanisms mediating sustained attention performance. One of these tasks is

[1] Department of Electronic, Science, and Research Branch, Islamic Azad University, Bojnord, Iran.
[2] Department of Biomedical Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran.
[3] Department of Psychology, Faculty of Human Science, Arak University, Arak, Iran.
Correspondence should be addressed to A. Behzadnia
(e-mail: aminbehzadnia@gmail.com) and S. A. Chermahini
(e-mail: akbariso@yahoo.com, S-akbarichermahini@araku.ac.ir).

the conjunctive continuous performance test (CCPT) known as a good measure of sustained attention [15], and it was used in the present study.

Spectral powers of EEG alpha, beta, theta, and gamma rhythms are considered important parameters representing neural activities and processing mechanisms underlying cognitive performance in humans. A few studies were concentrated on the relationship between the EEG band powers and cognitive performance, specifically the performance in attention tasks [16–19]. The respective results and conclusions are based on the data related to performing sustained attention tasks, which measure memory as well. However, the CCPT was claimed to measure only sustained attention and not memory [15].

In this study, we wanted to explore the relations between the powers of EEG frequency components and sustained attention using a visual version of theCCPT.

METHODS

Participants. Twenty-five Iranian university students with normal or corrected-to-normal vision, all dextrals, were selected for this study. Five of them were excluded from the general group because of major movement artifacts, errors of omission and commission above 20%, or excessive noise. Thus, the data of 20 students (9 men) with the mean age of 23.3 ± ± 2.8 years were fully analyzed. All subjects were tested for handiness with the Edinburgh test, and all found right-handed.

Procedure. Situational variables (e.g., fatigue, mood, or health state) are known to considerably affect attention functions in general and vigilance in particular. Before the EEG recording, in order to control the effect of mood and mental health in this research, all participants were asked to fill in two mood scales (current and general mood) and the General Health Questionnaire (GHQ). All of them were checked for history or current presence of any major neurological/medical or psychological conditions that may significantly impress cognitive functioning. The experimental procedures including EEG recording and the sustained attention task were explained in detail. The CCPT-V was performed in about 12 min during EEG recording. Testing was performed within a morning/midday interval.

Current Mood Scale. As the mood state was shown to affects the cognitive performance [20, 21], the general and current mood state of participants before performing the CCPT-V and EEG recording was measured. A version of the mood scale in Persian, similar to that in [22], was used to assess the current mood before recording of the data. The items of this scale assess the following adjective pairs: happy–sad, energetic–somber, and excited–exhausted. Participants were asked to rate their current mood state in a nine-point Likert scale.

Positive and Negative Affect Scales (PANAS). The PANAS [23] is a 20-item self-report mood scale that measures the general state (“How do you feel generally?”), positive affects (PA), and negative affects (NA). It comprises of 10 positive and 10 negative adjectives rated on a Likert scale, from 1 (very little or not at all) to 5 (very or extremely). We used a Farsi version of the scale with high internal consistencies for the PA and NA subscales (Cronbach’s alpha = 0.84 and 0.80, respectively) [24].

General Health Questionnaire (GHQ-28). A Farsi version of GHQ-28 was used in this study. This instrument is a self-administrative questionnaire capable to detecting minor non-psychotic psychiatric disorders in the general practice. The questionnaire comprises four subscales of (i) somatic symptoms, (ii) anxiety and insomnia, (iii) social dysfunction, and (iv) severe depression. Each subscale consists of 7 statements (28 statements in total). The questions were to be answered on a Likert scale. The subjects would get from a zero point (if they chose “not at all”) to three points (for “much more than usual”) responses. Participants in our study were asked to compare their recent psychological state with their usual state. Total scale score ranges from 28 to 112, and the cut-off point based on [25] is score 23; the higher the score, the poorer the psychological well-being. The GHQ-28 reported has a good reliability in the Iranian population [26]; Cronbach’s alpha was 0.85 [25].

CCPT-V. As was shown in some studies [27, 28], the performance in the auditory versions of the continuous performance task (CPT) was poorer than in the visual ones. Regarding the CCPT, Shalev et al., [15] concluded that the performance (as was measured in M-RT and s.d.-RT; see below) in the visual version of the CCPT was significantly better than in the auditory version of the task. Therefore, our focus was on the data of the CCPT visual version.

The CCPT-V was developed to assess sustained attention in the visual modality [15]. The test consisted of a single block of 320 trials preceded by 15 practice trials. The stimulus in each trial was a colored geometric shape presented at the center of the screen.

The size of each stimulus ranged from 1.4 to 1.8 cm in height and from 1.8 to 1.9 cm in width. The test included 16 different stimuli created from all possible combinations of four shapes (square, circle, triangle, or star) and four colors (red, blue, green, or yellow). The target red square appeared on 30% of the trials. A non-red square appeared in 17.5% of the trials, a red non-square appeared in 17.5%, and in the remaining 35% of the trials a shape that was neither squared nor red was presented. Each stimulus was presented for 100 msec and separated from the next by interstimulus intervals (ISIs) of 1000, 1500, 2000, or 2500 msec with each ISI appearing in 25% of the trials. Both stimuli and ISIs were selected randomly. Participants were instructed to respond, by right-clicking the mouse button, as soon as the target appeared and to withhold responses to all other stimuli (Fig. 1). All stimulus and task constructions were exactly the same, as the original one developed by Shalev et al [15]. The task was designed in Psytask software.

Performance Measures of the CCPT-V. Four performance measures were computed for the CCPT-V including: (i) Mean reaction time for correct responses (M-RT); (ii) standard deviation of the reaction times (s.d.-RT); (iii) percent of omission errors (omission of the target stimulus), and (iv) percent of commission errors (identification of a non-target stimulus as the target). The first two measures (RTM and s.d.) were related to the response time, and percentage of omission and commission errors reflect different aspects of accuracy of the response. All four measures are known to be sensitive detectors of lapses in sustained attention (see [15]).

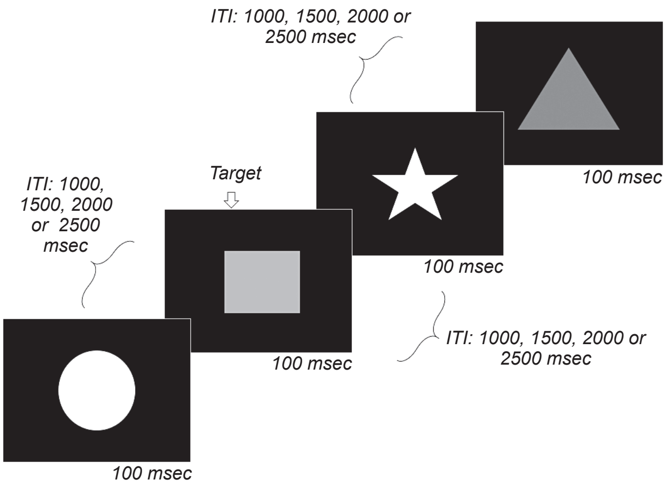


Fig. 1. Sequence of trials in the conjunctive continuous performance test-visual (CCPT-V).

Р и с. 1. Послідовність проб при реалізації візуальної версії тесту спільного тривалого виконання (CCPT-V).

The mean response time (M-RT) observed for the CCPT-V task in our study was 382 msec (s.d. = = 70 msec). This response time is shorter than those reported for CCPT-V in [15] (M-RT = 409 msec and s.d. = 56 msec; an original report on this task. All our participants were university students, while a sample in [15] included a group of university and a group of high-school students. This situation might explain somewhat faster reactions in our research. The mean percentages of omission and commission errors were low (0.45 and 1.6%, respectively).

The participants were divided into two groups using the media-split procedure based on their performance in the CCPT-V (good and weak groups) (Table 1).

Comparability of the Groups. A set of the *t*-tests was conducted to check whether the two experimental groups were comparable in terms of mood, age, and general psychological health before EEG recording. There was no hint to any pre-experimental difference between the two groups with respect to both positive and negative subscales of PANAS and current mood state; all *P* values were grater than 0.05 (Table 2).

T a b l e 1. Parameters of the Performance in the Experimental Groups of the Participants

Т а б л и ц я 1. Параметри виконання тесту в експериментальних групах обстежених

Measures of the CCPT-V	Total (n = 20)	Weak (n = 10)	Good (n = 10)
M-RT(msec)	382 (70)	404 (71)	360 (62)
s.d.-RT (msec)	60.7 (8.9)	67 (7.3)	55 (6.2)
omission	0.45 (0.99)	0.7 (1.3)	0.2 (0.63)
commission	1.6 (1.5)	1.3 (1.1)	1.9 (1.8)

T a b l e. 2. Means and (s.d.) for the Pre-experimental General Mood State (PANAS, positive and negative scales) and Current Mood State in the Two Experimental Groups

Т а б л и ц я. 2. Значення середніх та стандартних відхилень (у дужках) характеристик загального стану настрою (PANAS, позитивна та негативна шкали) та поточного стану настрою в двох групах перед експериментом

State mood index	Weak group (n = 10)	Good group (n = 10)
PANAS-PA	33(9)	38(5)
PANAS-NA	23(6)	26(8)
Current Mood	13(6)	11(5)

T a b l e 3. Means and (s.d.) for the Pre-experimental General Psychological Health State (General Health Questionnaire, GHQ-28) and its four subscales in the Two Experimental Groups

Т а б л и ц я 3. Значення середніх та стандартних відхилень (у дужках) характеристик загального стану психологічного здоров'я в двох групах перед експериментом

General health index	Weak group (*n* = 10)	Good group (*n* = 10)
Somatic symptoms	5 (2.8)	6.3 (3.4)
Anxiety and insomnia	6 (4.2)	5.3 (3)
Social dysfunction	7.2 (3.5)	7.2 (2.5)
Severe depression	2.4 (0.7)	3.4 (1)
Total score	21 (11)	21.2 (7.6)

In terms of general psychological health, two groups did not show any significant difference in total score of the GHQ-28 and in any of the four subscales (somatic symptoms, anxiety and insomnia, social dysfunction, and severe depression); all P values >0.05 (Table 3).

The two groups, in terms of age, were comparable (good group, M = 22.6, s.d. = 2.4, and weak group, M = 23.9, s.d. = 3.2); $P > 0.05$.

EEG Recording. EEGs, as well as blinks and saccades, were recorded with Ag-AgCl electrodes attached to the scalp sites Fz, Pz, and Cz according to the international 10–20 system [29]. Two reference electrodes were placed on the right and left earlobes. The data were collected using a Mitsar-202-32 channel differential amplifier. The EEG data were sampled at 250 sec^{-1} with the impedances typically below 10 kΩ and band-pass filtered from 0.5 to 70 Hz for the analysis.

Prior to EEG recording during performing the CCPT-V, EEG was recorded under two conditions, eyes closed and eyes open, at the resting state [30, 31]. During recording, participants were comfortably seated in a dimly light, sound-attenuated, and electrically shielded environment. First, each participant kept the eyes-closed state for 3 min without thinking of anything, being in a fully relaxed state. Second, the participants needed to keep their eyes open for another 3 min, while focusing on a white cross in the middle of the block screen without any instruction and staying in a fully relaxed state. After 2 min, the participants were instructed to perform the CCPT-V started with a trial block containing of 16 stimuli.

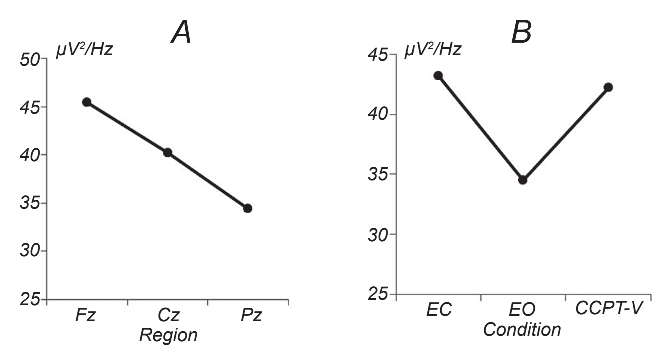
EEG Analysis. The data were analyzed by Matlab V. 2011a. Since some signals were affected by blinking and movement artifacts, and their amplitude was higher than ±100 μV, they were omitted from the consequent EEG analysis. After identifying the artifacts, the entire peaks including those were omitted. Then, the absolute spectral power was calculated for the signals recorded in each channel using the Welch method with the Hanning window having a length of 2 sec and 50% overlap. It should be mentioned that all calculations of the absolute power have been done for the theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–60 Hz) frequencies.

Statistical Analysis. The EEGs were analyzed in four above frequency bands and in three channels (Fz, Cz, and Pz). A set of 2 (group, weak vs. good performance in the CCPT) × 3 (condition, eyes-open, eyes-closed, and CCPT performing) × 3 (region, Fz, Cz, and Pz) repeated-measures MANOVA was performed to examine changes in EEG under three conditions for two groups separately and for four EEG frequency bands (rhythms).

RESULTS

The Mauchly's test indicated that the assumption of sphericity had been violated, therefore, degrees of freedom were corrected using the Greenhous–Geisser estimate of sphericity.

Theta Range. A significant global effect of the cortical region was observed with respect to this component; F (1.3, 23) = 21.14, $P < 0.001$. This result shows that the theta power was different in the three regions of Fz, Cz, and Pz (Fig. 2A), with a greater

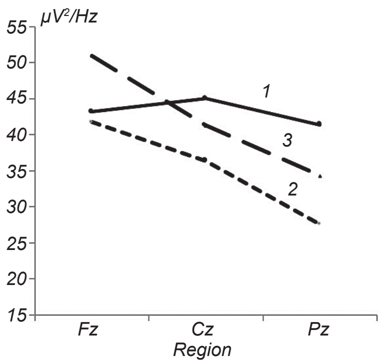


F i g. 2. Means of the theta power: A) in three cortical regions, Fz, Cz, and Pz, and B) under three conditions, eyes closed (EC), eyes open (EO), and performing the CCPT-V task.

Р и с. 2. Середні значення потужності коливань тета-ритму в трьох кортикальних зонах (Fz, Cz та Pz, *A*) та при трьох умовах тестування (очі заплющені, очі розплющені, виконання задачі CCPT-V, *B*).

power in region Fz. There was also a nearly significant main effect of the conditions F (1.5, 27) =3.4, $P <$ < 0.059 (Fig. 2B), with higher powers under EC and CCPT-V performing conditions and a lower power under EO condition.

There was highly significant interaction between the region and condition; F (2, 37) = 23.1, $P < 0.001$. This situation shows that the profiles of the theta power in the three regions were different during the above-mentioned three conditions (Fig. 3). There was no noticeable difference in the theta power with eyes closed in the three regions. A switch from the eyes open to task performing condition corresponded to a different scenario, with the greater theta power in the Fz and less in the Pz region. A set of paired-sample



F i g. 3. Means of the theta power differences in three regions (Fz, Cz, and Pz) under three conditions (EC, EO, and CCPT-V performing, 1–3, respectively).

Р и с. 3. Середні значення різниць потужності тета-коливань у трьох зонах (Fz, Cz та Pz) при трьох умовах тестування (*1–3*).

t-tests was conducted to compare the rate of the theta power in EO and performing CCPT-V in regions Fz, Cz, and Pz.

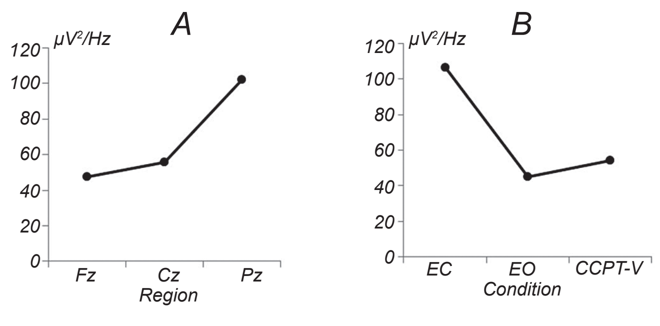
There was a significant difference in the theta power in region Fz for EO (M = 41.8, s.d. = 18.7) and CCPT-V (M = 51, s.d. = 25.3) conditions; t (19) = = 2.73, P = 0.013. A significant difference was also observed in region Cz for EO (M = 34.4, s.d. = 16.0) and CCPT-V (M = 41, s.d. = 22.7) conditions; t (19) = 3.2, P = 0.005. There was also significant difference in the Pz site for EO (M = 27.5, s.d. = 17.4) and CCPT-V (M = 34.0, s.d. = 27.0) conditions; t (19) = 2.76, P = = 0.012.

As is shown in Fig. 3, the participants demonstrated higher theta powers compared to the eyes-open condition in all three regions.

Alpha Range. A significant global effect of the region was observed, F (1.1, 18.3) = 11.68, $P < 0.01$. This effect indicates that the alpha power was different in the three regions (Fz, Cz, and Pz; Fig. 4A), with a greater power in region Pz. There was also a significant main effect of the condition; F (1.1, 18.9) = 11.68, $P < 0.01$ (Fig. 4B); it means that the alpha power was significantly different for eyes-closed, eyes-open, and CCPT-V performing conditions, with the higher power under EC condition and lower power with EO.

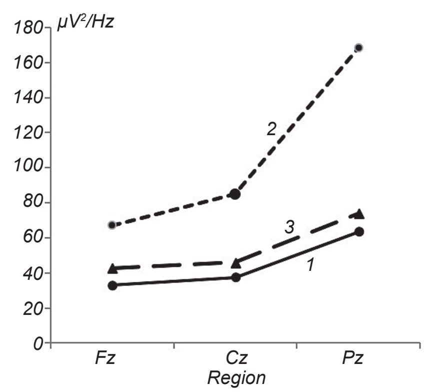
There was significant interaction between the region and condition; F (1.1, 18.9) = 11.68, $P < 0.01$. This effect is indicative for the fact that the profiles of alpha power in three regions were different during EC, EO, and CCPT-V performing (Fig. 5).

As it is illustrated by Fig. 3, a higher alpha power was related to the eyes-closed condition in region Pz.



F i g. 4. Means of the alpha power: A) in three cortical regions, Fz, Cz, and Pz, and B) under three conditions, eyes closed (EC), eyes open (EO), and performing the CCPT-V task.

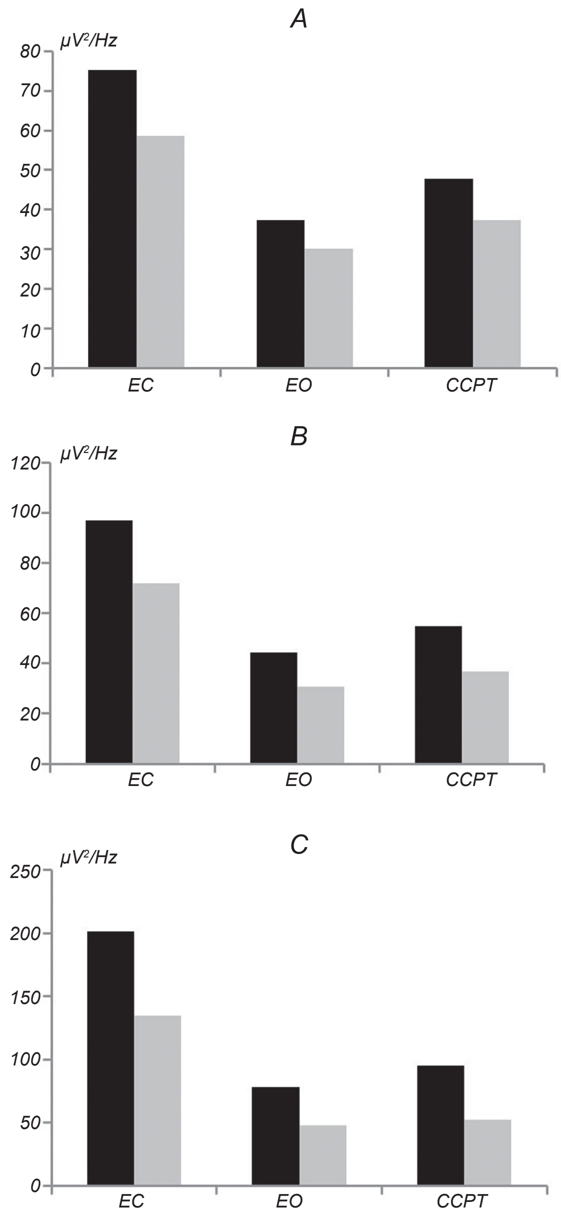
Р и с. 4. Середні значення потужності коливань альфа-ритму в трьох кортикальних зонах Fz, Cz та Pz (*A*) та при трьох умовах тестування (очі заплющені, очі розплющені, виконання задачі CCPT-V (*B*).



F i g. 5. Means of the alpha power differences in three regions (Fz, Cz, and Pz) under three conditions (EC, EO, and CCPT-V performing, 1–3, respectively).

Р и с. 5. Середні значення різниць потужності альфа-коливань у трьох зонах (Fz, Cz та Pz) при трьох умовах тестування (*1–3*).

Comparing of the CCPT-V performing state that with the eyes open showed that the greater alpha power was observed in all three regions, but the difference did not reach the level of statistical significance ($P > 0.05$).



F i g. 6. Means of the alpha power under three conditions (EC, EO, and CCPT-V) in three regions (Fz, Cz, and Pz; A – C, respectively) in two groups of subjects with weak and good performance in the CCPT-V task (filled and gray columns).

Р и с. 6. Середні значення потужності коливань альфа-ритму в трьох кортикальних зонах Fz, Cz та Pz (*A–C*) при трьох умовах тестування (очі заплющені, очі розплющені, виконання задачі CCPT-V) у двох групах тестованих з успішним та менш успішним виконанням тесту CCPT-V (темні та світлі стовпчики відповідно).

There was no significant effect of the group on both condition and region ($P > 0.05$), but Fig. 6 demonstrates that the group with better performance in the CCPT-V showed lower alpha powers sunder all three conditions and in three regions, specifically in the PZ region.

Beta and Gamma Ranges. There were no significant main effects of the region and condition; no interactions and group effects were observed for the beta- and gamma- range powers (all $P > 0.05$).

DISCUSSION

The aim of our study was to elucidate whether the performance in a sustained attention measure (CCPT-V) can be predicted according to the pattern of cerebral electrical activity. In this regard, the EEG data related to four frequency ranges, namely theta, alpha, beta, and gamma, in three regions of the brain (Fz, Cz, and Pz) were analyzed. The overall pattern of the outcomes allows us to draw two conclusions.

First, there were no significant effects related to the gamma and beta band powers. So, the results related to the theta and alpha bands are in our focus here. As to the theta power, there was a significant main effect of the region. It means that the theta power was different in three regions, Fz, Cz, and Pz (Fig. 2A), with the highest power in region Fz and the lowest power in Pz. There was also significant interaction between the region and condition. This effect tells us that the profiles of the theta power in three regions were different during EC, EO, and CCPT-V performing (Fig. 3). Results of pair-wise comparison showed that the participants demonstrated significantly greater theta powers in all three regions, while they performed the CCPT-V compared to the eyes-open condition.

This finding is consistent with the results of previous studies where it was found that increases in the theta-band activity is associated with sustained attention [19]. More pronounced increase in the theta power was observed in the frontal midline during performing the sustained attention task [18].

Regarding to the alpha power, our results showed significant differences in the three mentioned regions (Fig. 4A), with a greater power of this range in region Pz. There was a significant main effect of the condition (Fig. 4B); it means that the alpha power was dissimilar for the EC, EO, and CCPT-V conditions, with higher powers sunder EC condition and in the Pz area. These results are in line with the results of EEG and fMRI studies. It is well known that EEG alpha activity decreases in the eyes-open and increases in the eyes-closed state [32]; a decrement of the alpha band power is at least 20%, on average, in the eyes-open compared to the eyes-closed state. It has been suggested that increases in the alpha range refer to reduced, in general, activity of the brain. *Vice versa*, decreases in it refer to the intensifying brain activity [31]. Higher alpha powers in the central and posterior cortical regions are associated with omissions [33]. It has been shown that the alpha power decreases during performing the CPT (a very common task of sustained attention) [16]. In our study, however, no significant change in the alpha power was observed under CCPT-V condition.

Second, there was no statistically significant effect of the group on either the condition or the region ($P > 0.05$). Looking at the Fig. 6, we, however, see that the group with better performance in our task (CCPT-V) demonstrated lower alpha powers under all three conditions and in three regions, specifically in region Pz. In a pair-wise comparison, individuals with a good performance in the CCPT-V showed a significant decrease in the alpha power in the performing-task situation compared to the eyes-closed state, while this difference was insignificant in the weak-performance group. From all this facts, we may conclude that, in general, a greater decrease in the alpha power is associated with better performance in the sustained attention task.

Our findings showed that the alpha and theta spectral powers are related to sustained attention to some degree. Thus, characteristics of EEG activity associated with this type of attention give certain valuable information for understanding the neuronal mechanisms underlying this critical cognitive function, and also for better understanding of neuropsychiatric disorders characterized by impairments in attentional functions.

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All tests were carried out in accordance with the international standards for neurophysiological and neuropsychological research carried out with the involvement of humans. Written informed consent was obtained from all individual participants included in the study. The protocol was approved by the local Ethical Committee (Islamic Azad University, Department of Electronic, Bojnord, Iran).

А. Безаднія[1], М. Гхошуні[2], С. А. Чермахіні[3]

ЕЕГ-АКТИВНІСТЬ ТА ТЕСТУВАННЯ СТІЙКОСТІ УВАГИ

[1] Ісламський університет Азад, Боджнорд (Іран).
[2] Філія Ісламського університету Азад в Мешхеді (Іран).
[3] Аракський університет (Іран).

Р е з ю м е

Ми досліджували відношення між характеристиками ЕЕГ-активності та рівнем постійної уваги у людей. Візуальна версія тесту спільного тривалого виконання (CCPT-V) була використана як міра постійної уваги. В дослідження були залучені 20 студентів-добровольців університету; відповідно до результатів тесту вони були поділені на дві групи – успішну та менш успішну. Було проаналізовано спектральну потужність чотирьох ритмів ЕЕГ (тета, 4–8 Г; альфа, 8–13 Гц; бета, 13–30 Гц та гамма, 30–60 Гц). Відведення здійснювалося від трьох точок (Fz, Cz і Pz) у трьох умовах (очі розплющені, очі заплющені, виконання CCPT-V). Результати MANOVA з повторними вимірюваннями показали істотну залежність потужностей альфа- та тета-активності (але не бета- та гамма-ритмів) від умов тестування та точок відведення. Вплив приналежності до різних груп не досягав рівня вірогідності, але група з успішним виконанням CCPT-V демонструвала дещо нижчі значення спектральної потужності коливань альфа-ритму. Зроблено висновок про те, що нейронні системи, відповідальні за генерацію альфа- та тета-коливань, відіграють важливу роль у забезпеченні стабільної уваги.

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