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EEG CORRELATES OF ATTENTION CONCENTRATION IN SUCCESSFUL AMATEUR BOXERS

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Parameters of EEG activities that could be related to a better attention concentration were compared in two groups of young men, one of which included adequately coached amateur boxers and another consisted of students that were not involved in boxing. The EEG signals were registered from the Cz point in accordance with the 10-20 system; the theta/beta and theta/sensorimotor rhythm (SMR) ratios proved to be especially important for purposes of analysis. Research media included a FlexComp Infinity coder and an EEG-Z sensor with an automatic impedance function. The results were evaluated by means of BioGraph Infinity. The obtained results allow us to conclude that adequately coached amateur boxers who are successful achieve lower theta/beta ratio and theta/SMR ratios than control group students not involved in boxing. One can suggest this is due to the better attention concentration in the boxers (despite posible head injuries) compared to the control group.

Keywords: amateur boxers, EEG, spectral composition, attention, theta/beta ratio, theta/SMR ratio.

INTRODUCTION

It is important for sport physiologists to search for approaches to overcome possible injuries in particular sport types and provide adequate prophylaxis with respect to such risks. This requires the introduction of objective instrumental techniques in the respective research area. Examination of boxers based on quantitative analysis of EEG activity was initiated as early as in the 1950s. Nowadays, such analysis provides evaluation of the weights of EEG activity within different frequency ranges for all brain areas; in most cases, fast Fourier transform (FFT) methods are applied.

Results of quantitative EEG analysis allow researchers to find certain correlations between some indices and a number of physiological phenomena and characteristics. In particular, the ratio between the amplitudes or spectral powers of oscillations belonging to the theta and beta ranges (theta/beta ratio) was found to correlate negatively with age and positively with errors in continuous performance tasks, such as the test of variables of attention (TOVA) or the integrated visual and auditory (IVA) test. In attention deficit/hyperactivity disorder (ADHD) patients, this index was found to be higher in comparison with the norm [1]. There are explanations why the level of attention also correlates with the theta/sensorimotor rhythm (SMR) ratio. The latter rhythm can be recorded from the central cortical zone and includes 12–20 Hz oscillations; thus, it partly overlaps the alpha range but is generated by different cerebral neuronal generators [2].

Boxing presents high risks for sportsmen's health, especially at low levels of technical skills [3, 4]. Brain injuries resulting from head blows can adversely affect brain function and have a number of negative consequences, including attention and concentration disturbances. Situations similar to that in boxing can be observed in some other sport types, but boxing is obviously more dangerous from this aspect. According to Mironova and Heifec [3], intensive and extensive indices (IIs and EIs, respectively) of the injury frequency in selected sports types are: for boxing,

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158.1 and 14.0, while those for football (soccer) are 5.0 and 4.4, respectively. This confirms the rather high injury frequency in boxing.

Cortical deficiency symptoms due to mild traumatic brain injuries (TBIs) are comparable to those observed in ADHD and mood disorders (disturbed memory, concentration, and attention, as well as changes in mood and socialization). Quantitative EEG analysis is a promising objective approach in the diagnostics of cerebral concussion consequences, and its efficiency reaches 96% [5]. It should also be mentioned that early detection of manifold negative alterations of cerebral electric activity following head injury or a brain concussion can lead to the implementation of adequate and effective therapies, including, in particular, EEG feedback (neurofeedback) techniques.

Attention is defined as consciousness concentrated on an object, situation, or phenomenon, which has characteristics determining the quality of perception and operational thinking, as well as that of making (right) decisions. Furthermore, adequate or unsatisfactory control of execution depends on the situation [6–8].

Two attention dimensions are distinguished, namely direction and scope of attention. In combat sports, a narrow external attention area becomes especially important as the sportsman's sensorimotor attention has to be focused on permanent control of the opponent's behavior. Quantitative EEG analyses can also be used in descriptions of different aspects of cognitive functions [9–12].

Sterman [13] listed a number of EEG markers for attention disorders in children and adults. These signs, also identified in other studies, include a theta (4–8 Hz) activity increase in the prefrontal, frontal, and sensorimotor cortices [1, 14–22]. Another marker is a noticeable reduction of the 12-20 Hz activity, known as the SMR, and increased alpha rhythm activity, mostly in the anterior cortical areas [15–17, 23].

Considering the above-described data, we selected the Cz lead for recording of ongoing EEG. All the above-mentioned phenomena are manifested in this area; localization of this site corresponds to the so-called central belt where EEG changes related to attention disorders are expressed most clearly.

We tried to reveal the relations between values of the theta/beta and theta/SMR ratios (attention-related indices) and sport achievements of the boxers, as well as to estimate whether long-term involvement in amateur boxing considerably affects neurophysiological correlates of attention and concentration.

METHODS

Participants. Two groups of participants, namely active high-scoring amateur boxers and students of the Physical Education and Sports University having other sport specializations, were formed. The first group included 36 successful nonprofessional Polish boxers (participants of high-level international competitions, medal winners of the Poland and European Championships). The mean age of this group was 20.77 years. Nineteen subjects had an amateur boxing experience of 5–7 years, while this was 8 to 10 years in 17 cases. The control group included 52 male students without up-to-date high scores or conspicuous sports achievements but active in common sports (mean age 20.38 years). During the preceding year, all research participants neither experienced head injuries resulting in loss of consciousness or a stay in the hospital, nor had taken drugs affecting cerebral electrical activity.

EEG Recording and Analysis. The EEG activity was recorded using a Flex Comp Infinity coder (Thought Technology Ltd., Canada) and an EEG-Z sensor with a built-in impedance measurement function. A low-pass filter with 50 Hz cut-off frequency was used. Biograph Infinity (version 5.1.4) and SPSS (version 19) software were used for data recording and analysis.

In accordance with the international 10–20 system, a bowl-shaped active electrode was situated in the Cz site. A referential electrode (A1) and a grounding electrode (A2) were attached to the left and right earlobes, respectively. Throughout the research, the interelectrode impedance remained below 5 kΩ.

EEG frequency ranges corresponded to those extensively used (delta, 1–4 Hz; theta, 4–8 Hz; alhpa, 8–12 Hz; SMR, 12–15 Hz; beta 1, 15–18 Hz, and high beta, 18–30 Hz). Values of the theta/beta and theta/SMR ratios were quotients of the amplitudes (μV) averaged within the respective frequency bands.

There were three measurement conditions, namely with eyes open, eyes closed, and with visual attention concentrated on a selected point; the recording time was 1 min for each condition. The subjects sat upright on a comfortable chair. When their eyes were open, they were instructed either to avoid concentrating their attention on some object (to watch, being 1.5 m away, the centre of a switched-off 17-inch LCD monitor screen) or to concentrate their attention on a black spot (diameter 2 cm) in the middle of the monitor screen,

RESULTS

Using the Kolomogorov–Smirnov test, we examined distributions of the EEG indices (amplitudes of the theta, SMR, and beta1 rhythms and theta/beta and theta/SMR ratios) measured in the boxers (n = 36) and control (n = 52) under three conditions (eyes open, eyes closed, and visual concentration on the point). In all cases, with no exclusion, it was found that the distributions did not differ significantly from the normal (Gaussian) ones. The asymptotic relevance level of all cases did not exceed 0.05. These results allowed us to use the parametric Student t-test with the T0 Lowene correction applied to two types of variances for intergroup comparisons of EEG indices.

The averaged (within groups) values of the amplitude of theta activity were noticeably greater in the group of boxers with eyes open and with concentration on the point (P = 0.014 and P = 0.028, respectively). The analogous indices with eyes closed exceeded somewhat those measured with eyes open, but the intergroup difference in this case was insignificant (P = 0.628) (Table 1; Fig. 1A).

The situation was opposite with respect to the mean amplitudes of the SMR rhythm. The respective values in the group of boxers exceeded those in the control group under all three experimental conditions used, and these differences were significant (P = 0.048, P = 0.051, and P = 0.047) (Table 1; Fig. 1B).

There were no statistically significant differences between the mean amplitudes of beta1 activity in the groups of boxers and control students under all three experimental conditions of EEG recording (for eyes open, eyes closed, and concentration on the point, P = 0.237, P = 0.356, and P = 0.169, respectively).

Noticeable intergroup differences were found for both theta/beta and theta/SMR coefficients. For the first above-mentioned ratio, values in the group of boxers and control were 2.45 vs. 2.75 (P = 0.008) with eyes open and 2.44 vs. 2.68 (P = 0.046) with concentration on the point. A similar difference was also noticeable with eyes closed (2.39 vs. 2.55), but in this case the difference did not reach the level of statistical significance (P = 0.218) (Table 1; Fig. 1C).

The situation was nearly analogous but even somewhat clearer with respect to the theta/SMR ratio. Under all three experimental conditions, this coefficient in the group of boxers was lower than that in the control group (eyes open, 2.12 vs. 2.50; eyes closed, 2.05 vs. 2.32, and visual concentration on the point, 2.07 vs. 2.41; P = 0.001, P = 0.032, and P = 0.03, respectively).

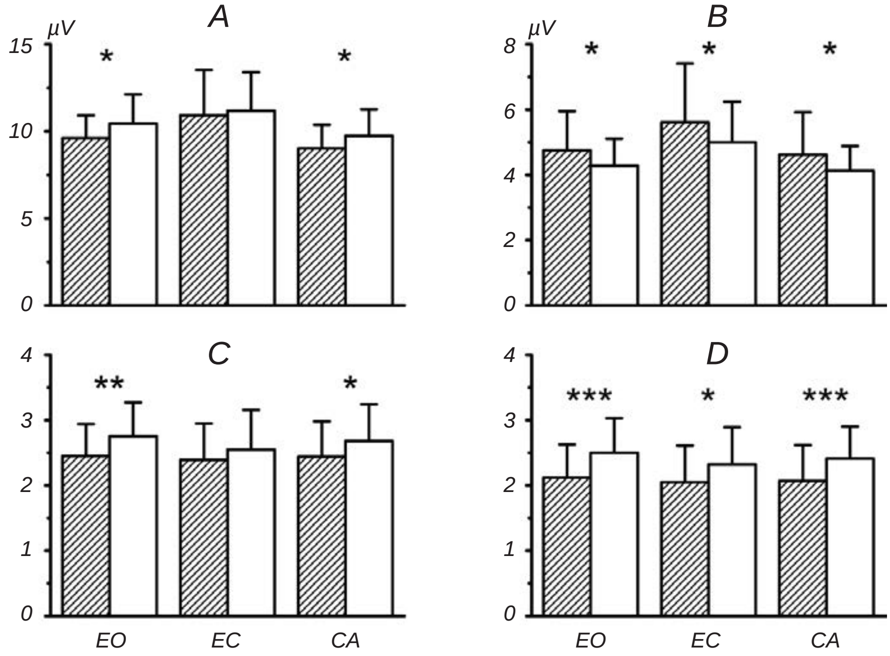
The control values assumed in this paper were the following: for the theta/beta ratio, 2.4 or less, and for the theta/SMR ratio, 2.0 or less.

Values of EEG indices in the groups of boxers and controls (students)

Значення показників ЕЕГ у групі боксерів-любителів та групі контролю

Research conditions	QEEG values	Boxers n = 36 mean	Students n = 52 mean	t-test (df = 86)	P value
Eyes opened	theta[a] (μV)	9.61	10.45	2.519	0.014*
	SMR[b] (μV)	4.75	4.28	–2.017	0.048*
	beta1[c] (μV)	3.92	3.73	–1.190	0.237
	theta/beta ratio	2.45	2.75	2.714	0,008*
	theta/SMR ratio	2.12	2.50	3.391	0.001*
Eyes closed	theta[a] (μV)	10.93	11.18	0.486	0.628
	SMR[b] (μV)	5.61	5.00	–1.911	0.051*
	beta1[c] (μV)	4.59	4.35	–0.928	0.356
	theta/beta ratio	2.39	2.55	1.241	0.218
	theta/SMR ratio	2.05	2.32	2.181	0.032*
Concentration on the point	theta[a] (μV)	9.02	9.74	2.238	0.028*
	SMR[b] (μV)	4.62	4.13	–2.031	0.047*
	beta1[c] (μV)	3.79	3.56	–1.386	0.169
	theta/beta ratio	2.44	2.68	2.028	0.046*
	theta/SMR ratio	2.07	2.41	3.028	0.003*

Footnotes: * the zero hypothesis has been rejected wherever the asymptotic relevance level is $P \leq 0.05$
[a] theta: 4-8Hz; [b] SMR: 12-15Hz; [c] beta1: 15-18Hz.



Comparison of EEG indices between groups of amatuer boxers and controls. A and B) Mean amplitudes (μV) of the theta and SMR rhythms, respectively. C and D) Mean values of the ratios of the beta/theta and theta/SMR amplitudes, respectively. Means ± s. d. are shown. Dashed and open columns correspond to the groups of boxers and controls, respectively. EO, EC, and AC denote conditions of EEG recording, open eyes, close eyes, and concentration of visual attention on the point, respectively. One, two, and three asterisks show cases of significant intergroup differences with $P < 0.05$, $P < 0.01$, and $P < 0.005$, respectively.

Порівняння показників ЕЕГ у групі боксерів-любителів та групі контролю.

DISCUSSION

The main findings of our study are the following. The mean amplitudes (and, respectively, the mean spectral powers) of theta-range EEG oscillations in the group of successful amateur boxers were, under all conditions of recording, noticeably lower than the respective average values in the group of students specialized in other sport disciplines. The situation with the SMR rhythm is opposite; the average amplitudes of oscillations of this frequency band were moderately but significantly higher in the group of boxers. The most interesting aspect, we believe, is that both the theta/beta and theta/SMR ratios were, on average, smaller in the boxer group than those in the controls. The respective differences were significant except those calculated for one of the recording conditions, namely with eyes closed. At the same time, it should be mentioned that the mean theta/beta ratio in boxers was somewhat lower than that in controls, and the insignificance of the difference was probably, first of all, related to considerable dispersions of the individual values.

Thus, the theta/beta ratio, called the “inattention index” by some researchers, is, as a rule, smaller in successful amateur boxers. This fact allows us to suppose that sensorimotor attention is better in boxers than in control subjects. In the boxer group, we did not find EEG manifestations typical of ADHD and the mood disorders that are interpreted as the result of mild traumatic brain injuries. The higher level of sensorimotor attention in boxers is probably determined by several factors. Among them, probably, is the primary selection of candidates for this sports specialization, but probably training to effectively concentrate the boxer’s attention on counteracting immediate blows thrown by the opponent also promotes a rise in the abilities of the respective cerebral structures to provide a higher attention level. It seems probable that this process neutralizes, in a certain sense, the results of mild traumatic brain injuries. These injuries, probably inevitable in boxing, are minimized by increasing the technical skills of the sportsmen. The above-described results appeared to us to be somewhat surprising. At the same time, these data confirm to a certain degree the conclusions by Brooks et al. [24] who revealed the absence of significant pathological alterations in EEG records of the successful amateur sportsmen (professional boxing is not widely accepted in Poland).

The authors of this paper intended to provide a simple and practical tool that could be used in diagnostics, monitoring, and selection of sportsmen and help in the prophylaxis and early detection of alterations within the brain (manifested in EEG activity) caused by head blows. It seems that two selected EEG indexes, namely the theta/beta and theta/SMR ratios can be useful from this aspect.

In this study, we looked at the possibility for implementation of the results in everyday work with sportsmen. Such work needs very short contacts with a number of sportsmen; thus, excessively complex investigation procedures are not expedient from this aspect. This is why we selected a single point, the Cz in our case, in order to enable fast and frequent control of the EEG parameters. It should be taken into consideration that all examined EEG indices are presented in this cerebral area.

Our finding that the boxers demonstrate, on average, lower theta (4–8 Hz) amplitudes and higher SMR (12–15 Hz) amplitudes deserves attention. Biofeedback (neurofeedback) EEG training is, in many cases, directed toward increase in the SMR activity. It is the most popular and frequently recommended biofeedback technique providing improved attention concentration and less effort in providing such concentration. Thus, we believe that the respective EEG biofeedback trainings can contribute to the maintenance of an adequate concentration level, resistance to stress, and better performance in competitions, as in the case of boxers.

The research discussed here is the first one in a series intended to reveal EEG markers that might prove useful in the diagnostics of sports achievements and facilitate health prophylaxis, including early detection of certain problems. Further research seems necessary and will involve other EEG indices.

Thus, the theta/beta and theta/SMR ratios in successful boxers differ from those observed in the control group of students. These results probably correlate with the greater ability of boxers to concentrate their sensorimotor attention. A significant negative influence of amateur boxing on the above EEG indices (which were assumed to increase due to intense head blows) obtained no confirmation in our study.

All examined persons, with no exception, were informed in detail about the study procedure and gave their written informed consent to participate in the tests. Thus, our study was carried out in accordance with the internationally accepted ethical principles for research work with humans.

The authors, A. Ziółkowski, A. Gorkovenko, M. Pasek, P. Włodarczyk, B. Zarańska, M. Dornowski, and M. Graczyk, confirm that they have no conflict of interest.

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ЕЕГ-КОРЕЛЯТИ КОНЦЕНТРАЦІЇ УВАГИ В УСПІШНИХ БОКСЕРІВ-ЛЮБИТЕЛІВ

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Р е з ю м е

Ми порівнювали показники ЕЕГ-активності, які могли мати відношення до кращої концентрації уваги, в двох групах молодих чоловіків. Одна з груп складалася з боксерів-любителів із високими спортивними показниками, а друга – із студентів-спортсменів, які не займалися боксом. ЕЕГ-сигнали відводилися від локусу Cz (відповідно системі 10–20); особливу увагу при аналізі приділяли відношенням потужностей тета/бета та тета/сенсомоторного (СМР) ритмів. До комплексу апаратури входили кодер FlexComp Infinity та сенсор EEG-Z із функцією автоматичного контролю імпедансу. Результати оцінювали за допомогою програми „BioGrapf Infinity”. Отримані результати дозволяють дійти висновку, що в адекватно тренованих боксерів-любителів (котрі досягали високих результатів на змаганнях) значення відношень тета/бета та тета/СМР у середньому є вищими, ніж такі у студентів з іншою спортивною спеціалізацією (група контролю). Незважаючи на можливі наслідки неминучих травм голови, для студентів-боксерів, вірогідно, є характерною краща концентрація сенсомоторної уваги, ніж для суб’єктів групи контролю.

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