Kickboxing on Theta and Beta2 waves: unravelling the mind's secrets through QEEG analysis

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Authors' Contribution:
- **A** Study Design
- **B** Data Collection
- **C** Statistical Analysis
- **D** Manuscript Preparation
- **E** Funds Collection

Received: 05 June 2023; **Accepted:** 27 November 2023; **Published online:** 14 December 2023

AoBID: 15929

Abstract

Background & Study Aim: Kickboxing is a sport based on striking with all limbs. The most contact-based variation of the sport is K1 rules. Research shows a deficit in the verification of the brain waves before the fight of the athletes. Therefore, the aim of the present study was to deepen the knowledge of the evaluation of Theta and Beta2 brainwaves before a kickboxing fight in the K1 formula.

Material & Methods: The study was conducted on a group of 15 kickboxing fighters specialising in K1 fighting principles. The participants were subjected to a diagnostic quantitative electroencephalography (QEEG), which allows the assessment of brain wave patterns. The QEEG test was conducted before the fight and participants were instructed in preparation for the test. Theta (4-8 Hz) and Beta2 (20-34 Hz) waves were examined at nine brain measurement points.

Results: Elevated normative Theta wave activity was found, particularly for the frontal band, and above-average Beta2 wave activity exceeding the normative range in each band. Comparative analysis of Theta and Beta2 waves showed statistically significant differences between testing with eyes open and eyes closed in selected leads (for Theta vs. C4, Pz, P3, P4 – $p<0.05$; for Beta2 vs. C4, P4 – $p<0.05$). Higher activity was shown relative to measurements with eyes closed.

Conclusions: The study showed above average and varied Theta and Beta2 wave activity according to eye condition in kickboxing fighters before a fight. The results suggest that athletes are focused and stimulated before a fight, which may affect their performance. This study may contribute to the development of new training methods for kickboxing fighters and brain injury prevention strategies.

Keywords: anxiety • brain waves • knockout • neurofeedback • prevention strategies • stress

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: The study was approved by the Ethics Committee of the University of Rzeszow, Poland (protocol code 8/12/2021)

Provenance & peer review: Not commissioned; externally peer reviewed

Source of support: Departmental sources

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Beta2 waves – are typically associated with alertness, attention, cognitive processes and mentally demanding activities. They are often observed during task focus, learning, problem solving, concentration and performance of tasks requiring precision [14].

K1 rules – the rules of kickboxing fighting, placing the least restrictions on the rules. In K1, all techniques found in kickboxing are allowed, performed without any limitation on the strength of the blows [1, 2].

QEEG (Quantitative Electroencephalography) – is an electroencephalography (EEG) analysis technique that uses advanced mathematical and statistical methods to quantify and image the electrical activity of the brain. QEEG is used to identify patterns of brain activity and assess brain and nervous system function [15].

Theta waves – is one of the five main brain waves observed during electroencephalography (EEG). Theta occurs in the frequency range of 4 to 8 Hz and is often associated with specific states of consciousness and brain activity [14].

INTRODUCTION

Kickboxing as a sport is one of the many types of combat sports based on striking with the upper and lower limbs. Competition in this discipline takes place according to various formulas and regulations, with the most popular fighting formulas being full contact and K1 [1]. The most effective and most common form of knockout is a direct blow to the head [2], making the neck and head area in kickboxing fighters the most injury-prone area [3]. Due to the nature of the sport, there are mechanisms that cause rapid acceleration and deceleration of the brain, including rotational (angular) acceleration, linear (translational) acceleration and deceleration after impact, which are the main mechanisms leading to concussion [4]. To date, it has not been described how the numerous blows to the head area, which are an integral part of the sport, and the long-term training process affect the cognitive states and processes associated with the different types of brain waves.

The most well-known and well-studied brainwaves are delta, theta, alpha, beta and gamma. One of the aims of this article is to describe and compare Theta waves, which occur during states of relaxation, meditation and in some forms of focused attention, and Beta2 waves, which are typically observed during mental activity, focused attention and complex cognitive tasks [5-7]. According to research, athletes have significantly more developed abilities and effective strategies for allocating greater attention compared to non-athletes, which contributes to better performance on complex tasks [8]. The relationship between brainwave activity and its actual impact on athletic performance and function is of great interest to researchers who seek to understand the mechanisms involved in these areas and the potential benefits for athletes, including kickboxing athletes. The results of these studies suggest that it is necessary to monitor and control brainwave activity in people who train professionally in sport. One possible means of assessing the electrical activity of the brain is quantitative electroencephalography (QEEG), which allows the assessment of brain wave patterns, frequency, amplitude and interactions between different brain areas [9, 10]. The device's electrodes are placed on the scalp and record the impulses generated by neuronal activity. The QEEG signals are then processed and analysed to identify specific brain wave patterns and properties. Studies based on the QEEG method have shown relatively higher Theta wave power values in the frontal area of the brain in athletes performing motor-cognitive tasks [5, 11, 8]. In contrast, oscillations in the beta frequency range are associated with the processing of movement-related information [12]. In one study conducted on kickboxing athletes using open-eye QEEG measurements, high Beta1 and Beta2 wave amplitudes were observed in the frontal lobe area, which according to the authors may be related to the accumulation of emotions that negatively affect judgement and coordination [13]. Another study assessing wave activity in kickboxing trainees, this time with eyes closed, also showed high intensity of SMR and Beta1 and Beta2 waves. According to the conclusions of this study, high activity of these waves can cause feelings of anxiety, stress, difficulty concentrating and reduced levels of physical activity [14].

The conclusions of this study indicate that specific brainwave activity can have both negative and positive effects on brain function and indirectly on sport performance. It follows that it is necessary to monitor and control brainwave activity in athletes. Unfortunately, at the moment there are few studies evaluating the effects of specific brainwaves on cognitive function in kickboxing athletes taking into account concomitant sport-related brain injuries. Conducting new research in this direction may contribute to the development of new training methods for kickboxing athletes and brain injury prevention strategies.

Therefore, the aim of the present study was to deepen the knowledge of the evaluation of Theta and Beta2 brainwaves before a kickboxing fight in the K1 formula.

MATERIAL AND METHODS

Study design

The study consisted of a QEEG diagnosis performed prior to a K1 kickboxing fight, taking into account the Theta and Beta2 waves. A group of 15 kickboxing fighters specialising in K1 rules were recruited. The athletes were informed about the purpose of the study, the methodology used, possible side effects and the possibility of withdrawing from the study at any stage without giving any reason, in accordance with the Declaration of Helsinki. Participants gave their written consent to participate in the study. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Rzeszow, Poland (protocol code 8/12/2021). The quantitative electroencephalography (QEEG) study was conducted on the morning of June 2022.

Participants

The athletes in the study were aged 24.33 ± 3.06 years, mean body mass was 82.0 ± 9.08 kg and body height was 179.26 ± 4.47 cm. Inclusion criteria for the study were training seniority, active competition starts, recommendation from the head coach and absence of injury and neurological diseases. Serious head injuries, skin diseases, epilepsy and neurological disorders were used as exclusion criteria.

QEEG Procedure

EEG (quantitative electroencephalogram) is a quantitative analysis of the EEG record, in which the data is digitally coded and statistically analysed using the Fourier transform algorithm. Each examination of one person lasted about 10 minutes and consisted of eyes open session – looking at the point least distracting to the examined person, as well as 10 minutes with eyes closed. The study was conducted in the EEG biofeedback laboratory in the morning. Each participant of the study was carefully instructed on how to prepare for the study (especially in terms of the number of hours of sleep on the day before: 7-8 hours, not drinking alcohol and coffee on the day and the day before the examination, not smoking cigarettes on the day of the examination and not taking medications before the examination). All participants were examined in a sitting position in a comfortable therapeutic chair. The wave amplitude and power for specific frequencies were analysed here. QEEG data were collected by measuring all waves from nine brain points (Cz, C3, C4, Fz, F3, F4, Pz, P3, P4), based on the international 10-20 system. The EEG signal was transformed using DigiTrack 15 software (Elmiko, Warsaw, Poland). In these experiments we focused on Theta (4-8 Hz) and Beta2 (20-34 Hz) waves. The amplitude of QEEG rhythms is calculated with medical standards by the DigiTrack apparatus. The signal spectrum is a representation of this signal's frequency. The FFT algorithm is used, with the result of the function:

$$f(z) = A(z) + j * F(z) \quad (1)$$

where **f(z)** represents the complex function of the EEG signal after transformation, indicating the signal at 'point z' which could be associated with either a time or frequency point of signal analysis. **A(z)** denotes the amplitude of the EEG signal at 'point z' reflecting the strength or intensity of the signal's oscillation at this point. The term **j** stands for the imaginary unit, symbolizing the square root of −1 and is utilized to depict the imaginary component of the signal, thereby facilitating the analysis of both the signal's amplitude and phase. Lastly, **F(z)** signifies the phase of the EEG signal at 'point z' relating to the time shift of the signal oscillation in comparison to a reference point, an aspect vital for grasping the synchronization of brain waves.

In FFT analysis, the following indicators have been implemented: minimal signal amplitude of 0.5 μV with minimal temporal distance between single maximal values of 0.5 Hz. The analysis was performed using a computing buffer of 8.2 s (2,048 assessment points, accuracy 0.12 Hz). As a result, the set of amplitude values for each defined part of the frequency spectrum has been obtained. The gap between single values, measured in Hz defines the calculation resolution according to the FFT algorithm; this indicator depends on signal sampling frequency and on the length of the computing buffer:

$$r = fs / N \quad (2)$$

where **r** is the calculation resolution, i.e., the gap between single records; **fs** signal sampling frequency; **N** length of computing buffer.

The results of spectrum analysis in the FFT panel in DigiTrack show peak to peak amplitudes. To ensure the appropriate reliability, the measurement epochs of several seconds have been implemented. The epoch length determines the frequency resolution of the Fourier, with a 1 second epoch providing a 1 Hz resolution (plus/minus 0.5 Hz resolution), and a 4 second epoch providing 0.25 Hz, or plus/minus 0.125 Hz resolution. The elimination of artifacts from the EEG recording was performed manually and automatically [15, 13, 14].

Statistical analysis methods

Statistical analysis of the collected material was performed using Statistica 13.3 package (TIBCO Software Inc, Santa Clara, USA). Descriptive statistics were calculated in the form of mean, arithmetic, standard deviation, median and lower and upper quartile. The choice of statistics was based on the results of the Shapiro-Wilk test in which the variables deviated from a normal distribution. Therefore, for comparisons of values with open and closed eyes, the Wilcoxon paired rank-order test was used. Statistically significant differences were considered to be $p<0.05$. In addition, box plots were prepared for statistically significant differences showing, median, 25th-75th percentile interquartile range, range of non-outliers.

RESULTS

When assessing the level of Theta waves in the 9 leads for open eyes, the highest activity was found at all measurement points for the frontal band (Fz, F3, F4). The same trend was observed for closed eyes (Table 1). Wavelet activity was in line with reference norms, while its value was closer to the upper limit of normal.

The comparative analysis illustrates statistically significant differences between the open-eye and closed-eye examinations, which were shown in the C4, Pz, P3, P4 leads. In other cases, the mean values were similar (Table 1 and Figure 1).

For Beta2 waves with eyes open, above-average cerebral activity was found relative to all measurement bands (frontal, parietal and occipital). A similar trend was observed for the measurement with the eyes closed. The value of all amplitudes exceeded the reference norms. The highest activity, in both measurement variants, was shown for the right frontal lobe – F4 (Table 2).

For the Beta2 waves, a statistically significant variation was noted with respect to the C4 and P4 leads – $p<0.005$ (Table 2 and Figure 2). In the other leads, however, the mean values differed without statistical significance (Table 2).

Table 1. QEEG results for 4-8 Hz Theta waves with eyes open and closed.

Theta 4-8 Hz	Open eyes					Close eyes					p
	X̄	SD	Med	Q1	Q3	X̄	SD	Med	Q1	Q3	
Fz	14.68	5.15	14.52	11.77	14.91	13.96	4.23	14.52	11.77	14.91	0.65
F3	13.40	4.01	12.26	11.78	13.70	12.45	1.91	12.26	11.780	13.70	0.18
F4	13.45	3.57	12.14	11.91	14.72	12.79	2.27	12.14	11.91	14.37	0.17
Cz	8.60	1.68	8.51	7.38	10.10	8.86	1.65	8.51	7.38	10.10	0.65
C3	8.18	1.67	7.64	6.77	9.07	8.44	1.70	7.64	6.77	10.59	0.65
C4	7.23	1.45	6.71	6.58	8.08	8.97	2.58	8.08	6.71	11.78	**0.02**
Pz	7.15	1.68	6.85	5.25	8.17	8.56	2.310	9.66	6.08	10.62	**0.02**
P3	7.52	1.53	6.62	6.54	9.45	8.78	1.76	9.84	6.62	10.12	**0.01**
P4	6.31	1.56	5.25	5.11	7.87	8.53	1.98	9.66	7.25	10.08	**0.01**

X̄ arithmetic mean; **SD** standard deviation; **Med** median; **Q1** bottom quartile; **Q3** upper quartile; ***p*** level of significance for differentiation; **Fz** central frontal electrode; **F3** left frontal electrode; **F4** right frontal electrode; **Cz** peak central electrode; **C3** left central electrode; **C4** right central electrode; **Pz** central occipital electrode; **P3** left occipital electrode; **P4** right occipital electrode.

Note: statistically significant values have been bolded

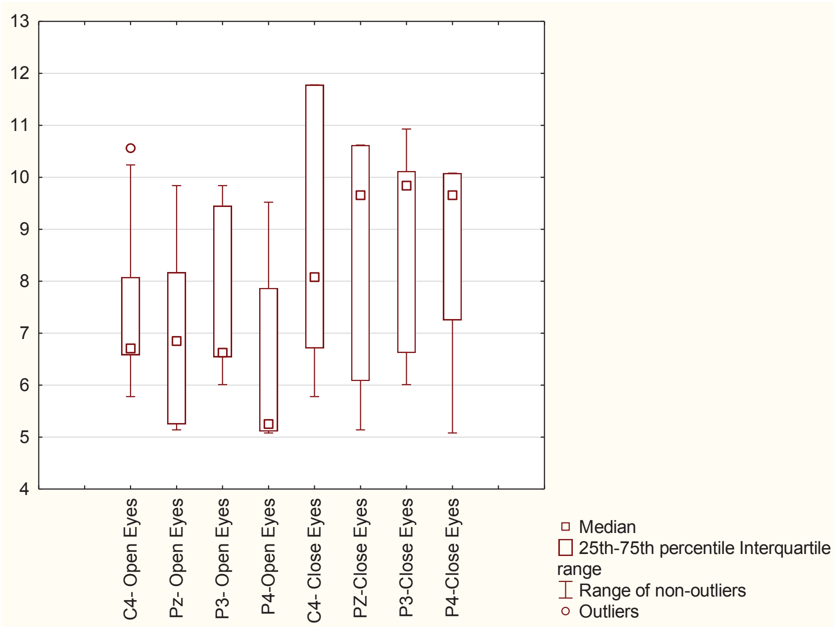

Figure 1. Descriptive theta statistics for the leads in which a statistically significant difference was shown between the study with eyes open and closed.

Table 2. QEEG results for Beta2 20-35 Hz waves with eyes open and closed.

Beta2 20-35 Hz	Open eyes					Close eyes					*p*
	X̃	SD	Med	Q1	Q3	X̃	SD	Med	Q1	Q3	
Fz	6.55	0.56	6.50	6.16	6.96	6.75	0.76	6.50	6.16	7.50	0.20
F3	8.35	1.81	8.47	7.31	9.41	8.19	1.21	8.47	7.31	9.41	0.68
F4	9.52	2.85	9.29	7.08	12.56	9.16	2.44	9.29	7.08	11.17	0.17
Cz	6.78	0.52	6.72	6.25	7.49	6.80	0.68	7.04	6.25	7.49	0.59
C3	7.11	0.63	7.24	6.40	7.64	7.30	0.81	7.40	6.40	7.64	0.10
C4	7.35	0.67	7.39	6.69	7.89	7.63	0.82	7.81	6.76	7.89	**0.04**
Pz	7.15	0.74	7.28	6.38	7.81	7.36	0.90	7.39	6.38	7.81	0.10
P3	7.91	0.63	8.10	7.10	8.46	8.25	0.84	8.62	7.46	8.79	0.08
P4	7.34	0.99	7.60	6.14	8.06	8.31	0.92	8.69	7.99	8.79	**0.01**

X̃ arithmetic mean; **SD** standard deviation; **Med** median; **Q1** bottom quartile; **Q3** upper quartile; ***p*** level of significance for differentiation; **Fz** central frontal electrode; **F3** left frontal electrode; **F4** right frontal electrode; **Cz** peak central electrode; **C3** left central electrode; **C4** right central electrode; **Pz** central occipital electrode; **P3** left occipital electrode; **P4** right occipital electrode.

Note: statistically significant values have been bolded

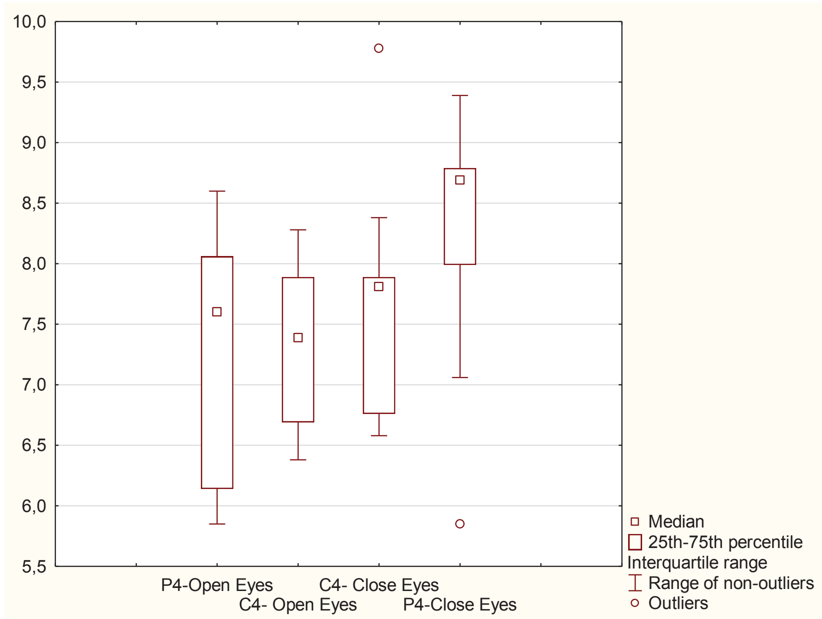

Figure 2. Beta2 descriptive statistics for leads showing a statistically significant difference between open and closed eye testing.

DISCUSSION

By characterising the recorded results for the Theta waves in the open-eye and closed-eye condition, elevated brain activity can be seen at selected measurement points. The interpretation of the elevated Theta wave amplitudes is not straightforward. This state is related to emotional processes, i.e., on the one hand, it may result from strong arousal, and on the other hand, it may be related to a state of inner focus and relaxation, which promotes psychological preparation for combat [16, 17]. Athletes show varied mental preparation immediately before a confrontation. Some are stimulated, focused and concentrated by picturing in their mind the task ahead and possible scenarios, while others seek to achieve a state of deep relaxation, detachment in order to consume energy at the right time [13]. Both a state of over-stimulation and deep apathy are not beneficial to the athletes' starting activity. The best form of pre-start disposition is optimal arousal. Interestingly, higher power Theta amplitudes in the frontal-central line may also be associated with better performance by athletes [8]. The results recorded for the frontal lobe showed the highest activity (Fz, F3, F4). On the basis of the analysis of the mean values, it can be seen that the subjects presented normative values, while their weight was close to the upper limit of the reference norms. Higher theta activity in the frontal lobe may also be related to stress reactions and anxiety. This area plays a role in the regulation of emotions and stress responses [18, 7]. The observed trend in relation to kickboxing athletes may be due to increased emotional activation, i.e., counteracting the excessive anxiety and stress associated with a future clash with a rival.

When assessing Beta2 wave amplitudes, above-average results were observed in relation to their activity. In our study, the values of all the leads were above the reference norms for this wave. Increased Beta2 activity may be associated with concentration, attention, analytical thinking, planning or performance of both mental and motor tasks, where decisiveness and quick decisions are required [19, 20]. In addition, it may be affected by stress, anxiety [21] as well as insomnia [22, 23]. Again, it seems that the reason for the higher Beta2 activity in the kickboxers studied is the overall preparatory pathway preceding the sporting confrontation. The athlete, in a focused training process, experiences intensive training sessions in which new skills, knowledge or views are acquired. Such activity requires, among other things, intelligence, strong concentration, attention and decisiveness in decision-making. Being on this path, he is exposed to many pitfalls (including overtraining, dehydration, malnutrition, inflammation, sparring pressure), which can be related to insomnia and stress. In addition, in the period immediately before a fight, there is a so-called internal battle with oneself, where vigilance, focus on the task or stress and anxiety before a momentous event are intensified. The excessive brainwave activity associated with this can lead to feelings of over-focus, stress, anxiety, difficulty concentrating, impaired motor responses and impaired alertness [13, 14]. Our own findings regarding Theta and Beta2 activity are similar to those shown for a community of kickboxers, studied in a different context and timeframe [13, 14].

Comparative analysis of brain electrical activity by quantitative electroencephalography (QEEG) in the open-eye and closed-eye condition showed variation, with signs of statistical significance for mean Theta waves, in the right central lobe and in all leads for the parietal lobe (C4, Pz, P3, P4 – Table 1). The same results were noted for Beta2 amplitudes, relative to the right central and parietal areas (C4, P4 – Table 2). Higher activity was found for these areas relative to measurements with the eyes closed.

QEEG with eyes open records brain activity during the reception of external stimuli, involving the visual sense or its synergy with other senses. This occurs during various tasks, i.e., observing a phenomenon, listening attentively to sounds, or performing a new task, and the brain activity is focused on processing external information. In this case, higher frequency waves may co-occur with the activation of cognitive processes and sensory perception [24]. In relation to a combat sports athlete including a kickboxer, this can occur after fighting a demanding sporting bout, realising training content aimed at acquiring new technical skills or be the result of a long-term impact of the training and competition process [25, 26, 14]. In contrast, the closed-eye variant eliminates the registration of the external environment, which can lead to multifaceted changes in brain activity [7, 14]. There are processes directed at, inter alia, rest, regeneration, relaxation, meditation favouring lower activity, while increased brain activity may be associated with intense creativity, focus, alertness, concentration. For the combat sports athlete, the period of direct competition preparation, is associated with a decreasing volume of training load (so-called tapering) [27, 28], favouring the body's broadly understood repair processes. On the other hand, in the period immediately before the fight, there is a multifaceted visualisation of the confrontation, which is associated with an in-depth analysis and planning of the tasks to be performed. The above discussion seems to explain to some extent the observed variation in the results of our own study. Our subjects were diagnosed immediately before the fight, where the higher values of amplitudes with eyes closed may have been influenced by their current emotional state. The specifics of competitive kickboxing force the athletes into a kind of mental state of combat readiness, characterised by a switching off of the mind to external stimuli not related to the upcoming confrontation. There is an increased concentration, focus, arranging a game plan in one's head and intense visualisation connected with the future realisation of planned tasks. Based on athlete-coach experience and empirical observation, it has been noted that this process occurs most often with eyes closed, often accompanied by music. Qualitatively inferring this type of phenomena may have an influence on the generation of higher activity amplitudes in the discussed areas of the studied kickboxers with eyes closed immediately before a sport fight.

CONCLUSIONS

Conclusions from our study for the collective of kickboxers immediately prior to a sporting bout indicate elevated activity of Theta amplitudes, particularly in the frontal band, albeit consistent with reference norms, as well as Beta2 wave amplitudes exceeding the normative range in each band. Inferring qualitatively, this may be a consequence of the broadly understood training process in the preparation period for the fight and the immediate combat readiness period itself before the fight, where positive and negative emotional states occur depending on the individual mental profiles of the athletes. In competitive combat sports, including kickboxing, too much activity of these waves can have a negative impact on success in competition.

Comparative analyses and their results, in the juxtaposition of measurements in the open – and closed-eye condition, showed significant differences in brainwave activity for Theta of the parietal and central right area and for Beta2 of the right central and parietal areas, with higher results in the measurement for the closed eyes. This suggests that the period of immediate combat readiness prior to combat may influence the increased activity of selected brainwaves in a particular variant of the study.

Practical implications

Monitoring and detailed analysis of the results from quantitative QEEG enables specialised diagnosis of the level of brainwave responses of combat sports athletes and, when necessary, provides great diagnostic value for planning therapeutic interventions to counteract excessive focus, stress, anxiety and difficulty maintaining attention and concentration. Ultimately, this type of action can have a positive impact on training and competition activities.

Limitations

Our study had some limitations, namely the diagnosis of brain activity was made using a single QEEG imaging modality. It is recommended that the diagnosis of brain activity of kickboxing athletes be expanded to include other imaging studies (i.e., computed tomography – CT, magnetic resonance imaging – MRI) or neuropsychological diagnosis, in order to capture the multifaceted clinical context and thus to provide a detailed diagnosis and understanding of the condition of the study population.

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Cite this article as: Rydzik Ł, Wąsacz W, Ambroży T et al. Kickboxing on Theta and Beta2 waves: unravelling the mind's secrets through QEEG analysis. Arch Budo Sci Martial Art Extreme Sport 2023; 19: 211-218