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Influence of Beta and Theta waves as predictors of simple and complex reaction times in examined groups of judo athletes during the Vienna test

Magdalena Pronczuk
Faculty of Physical Culture, Gdańsk University of Physical Education and Sport, Gdańsk, Poland,
nadsprawna@gmail.com

Tomasz Chamera
Faculty of Physical Culture, Gdańsk University of Physical Education and Sport, Gdańsk, Poland

Alicja Markiel
SWPS University, Katowice, Poland

Jerzy Markowski
Department of Laryngology, Faculty of Medical Sciences, Medical University of Silesia in Katowice, Poland

Jan Pilch
Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

See next page for additional authors

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Keywords

Beta waves, Theta waves, beta1/theta protocol, brain

Cover Page Footnote

Authors

Magdalena Pronczuk, Tomasz Chamera, Alicja Markiel, Jerzy Markowski, Jan Pilch, Piotr Żmijewski, and Adam Maszczyk

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Article

Influence of Beta and Theta waves as predictors of simple and complex reaction times in examined groups of judo athletes during the Vienna test

Magdalena PROŃCZUK[1]*, Tomasz CHAMERA[2], Alicja MARKIEL[3], Jerzy MARKOWSKI[4], Jan PILCH[5], Piotr ŻMIJEWSKI[6], Adam MASZCZYK[7]*

1 Faculty of Physical Culture, Gdansk University of Physical Education and Sport, Gdańsk, Poland; ORCID 0009-0005-1478-3151
2 Faculty of Physical Culture, Gdansk University of Physical Education and Sport, Gdańsk, Poland; ORCID 0000-0002-5381-7634
3 SWPS University, Katowice, Poland; ORCID 0009-0005-9233-583X
4 Department of Laryngology, Faculty of Medical Sciences, Medical University of Silesia in Katowice, Poland; ORCID 0000-0001-8963-4250
5 Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland; ORCID 0000-0002-2682-4708
6 Department of Physical Education, The Józef Piłsudski University of Physical Education, Warsaw, Poland; ORCID 0000-0002-5570-9573
7 Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland; ORCID 0000-0001-9139-9747

* Correspondence: nadsprawna@gmail.com; a.maszczyk@awf.katowice.pl

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Abstract: Introduction: This research aimed to investigate which waves, Theta or Beta, are significant predictors of visual simple and complex reaction times during the Vienna test, using regression modeling. The research material comprised the test results of male judo athletes (n = 24), selected through mixed sampling (purposive and random). The study was conducted in two cycles, differentiated by frequency but with the same duration of EEG biofeedback sessions, in both the control and experimental groups. The first cycle of the study consisted of 15 sessions held every other day. Each training session lasted for 4 minutes. The second series of studies, which took place after a six-week break, was characterized by a higher frequency of meetings (daily), with the duration of one training session remaining the same as in the previous cycle, i.e., 4 minutes. The impact of neurofeedback training on the visual reaction speed of judo athletes was verified using selected samples from the Vienna Test System (VTS). The study revealed that athletes from the experimental group, as a result of implementing the beta1/theta protocol, statistically significantly improved their simple and complex reaction times after each training cycle. Similar changes were not observed in the control group. The results suggest that neurofeedback training may significantly improve reaction skills in a sports context. However, for a fuller understanding and confirmation of these effects, further well-controlled studies are necessary.

Keywords: Beta waves, Theta waves, beta1/theta protocol, brain.

1. Introduction

The primary goal of the training process is to maximize the athletic achievements by refining athletes' technical and tactical skills and elevating their level of motor preparedness. In this journey towards achieving high sports results, psychological training focused on improving reaction time, which plays an increasingly significant role. The time and adequacy of reaction are fundamental predispositions of a judo athlete. Scientific findings thus far have suggested that an athlete's greater mental endurance, including their ability to focus under competitive pressure, significantly influences improved performance during competition [1, 2, 3, 4].

High concentration and the associated heightened alertness achieved under optimal arousal conditions of the nervous system streamline cognitive processes and reduce reaction times [5, 6, 7, 8]. An analysis of the relationship between athletes' self-regulation abilities and their world ranking conducted by Dupee et al. [9] demonstrated that better management of physiology and emotions distinctly correlates with sports performance. Athletes who could not control their reactions to stress and succumbed to distraction held lower positions in the overall rankings [9].

In sports like judo, where visual attention and its contribution to decision-making and planning the appropriate motor response are crucial for the athlete's success, a high level of concentration and the ability to react quickly to visual stimuli are particularly important. Numerous analyses related to assessing the effectiveness of EEG-biofeedback training based on self-control of the heart rate and breathing frequency have been conducted to enhance the efficiency of actions taken by athletes.

The introduction of EEG-biofeedback training among elite wrestlers significantly improved their reaction times by mastering the skill of maintaining an optimal heart rate rhythm [10]. Similar results were obtained in a group of basketball players, where EEG-biofeedback training in the experimental group led to a significant improvement in response time to stimuli compared to the placebo and control groups [11]. In light of these findings, the EEG-biofeedback method appears to be an interesting approach that can support the development of the crucial skill of selective attention in elite sports, influencing the athletes' speed of stimulus processing and their effectiveness.

Simultaneously, it seems reasonable to apply training time that is adequate to the time of sports competition in a specific discipline or sports event. Therefore, our research aimed to investigate which waves, Theta or Beta, are significant predictors of visual simple and complex reaction times during the Vienna test, using regression modeling.

2. Materials and methods

2.1. Participants

The research material comprised the test results of male judo athletes, selected through mixed sampling (purposive and random). Each athlete was a member of the Polish National Team and held either an International Master Class (MM) or National Master Class (M) – purposive selection. The study was conducted on a group of 24 athletes, randomly divided into two subgroups: experimental (n = 12) and control (n = 12). Table 1 presents the descriptive statistics of individual groups.

Table 1. Descriptive statistics of characteristic variables for judo athletes (mean and SD).

Parameters	**EG**	**CG**
Age (y)	22 (±3)	22 (±2)
Body mass (kg)	74.8 (±1.5)	75.3 (±2.2)
Body high (cm)	174.2 (±2)	174 (±2.5)
BMI	23.8 (± 1.6)	23.6 (±2.1)

EG – experimental group , CG – control group; BMI – Body Mass Index.

2.2. Procedures

All volunteers were healthy and were instructed to avoid taking medications, alcohol, and substances (such as caffeine and energy drinks) for 12 hours before the study. Additionally, within 24 hours prior to the examination, all volunteers were advised to refrain from strenuous resistance exercises. They were informed about the research protocol, potential risks, and benefits of the study, and then provided written informed consent to participate in the research. Respondents had the right to withdraw from the study at any stage of the experiment. The protocol was approved by the Bioethics Commission for Scientific Research at the Jerzy Kukuczka Academy of Physical Education in Katowice. Tests were conducted at the Human Psychomotor Laboratory of the AWF in Katowice, using the EEGDigiTrack MultiEEG_32 device.

The study was conducted in two cycles, differentiated by frequency but with the same duration of EEG biofeedback sessions, in both the control and experimental groups. The first cycle of the study consisted of 15 sessions held every other day. Each training session lasted for 4 minutes and was a modification of the Dupee training [12]. The second series of studies, which took place after a six-week break, was a modification of the Thompson training program [13], characterized by a higher frequency of meetings (daily), with the duration of one training session remaining the same as in the previous cycle, i.e., 4 minutes.

During each session, the percentage of time above the threshold was monitored, which was adjusted upward or downward for the reinforced and inhibited waves, so that the training difficulty level was optimal and adapted to the individual progress of each athlete. The basic training protocol in the experimental group was beta1/theta training, used to increase concentration and achieve the so-called "narrowing of attention" in athletes.

Before the start of the first and second training cycles, and after the completion of each cycle, simple and complex reaction times were assessed in both study groups. The control group followed the same schedule as the experimental group and had the same training duration and frequency. The preparation procedure for training was the same for both groups, but in the control group, instead of the beta1/theta protocol, an EEG simulation was displayed, independent of the brainwave patterns generated by the participant.

2.3. EEG biofeedback training

EEG biofeedback training was conducted using the EEGDigiTrack MultiEEG_32 device, whose quality was confirmed by ISO and CE certificates. Prior to EEG signal registration, the impedance level of electrodes and interelectrode levels were checked each time using the built-in impedance sensor. To initiate EEG biofeedback diagnostics and training, it was necessary to achieve an impedance level below 5 kΩ and inter-electrode measurements differing by no more than 1 kΩ.

Each training session in each cycle was preceded by a 3-minute single-channel diagnostic. During this time, participants were asked to perform the following tasks: sit with open eyes for one minute, sit with closed eyes for one minute, sit with open eyes with an additional activation task of counting down by 7 from 100. During the electrode reference diagnosis, the reference electrode was attached to the left earlobe, the grounding electrode to the right earlobe, and the active electrode at the Cz point, according to the international 10–20 system. During EEG biofeedback training, the active electrode was attached to the C3 point, allowing the main training goal to be achieved (developing the ability to maintain an optimal balance between the activity of fast (beta) and slow (theta) waves). During each EEG biofeedback session, the percentage of time above the threshold, which is the main measure of progress, was also monitored to optimize the training difficulty level for each athlete.

The recorded signals were filtered from 2 to 40 Hz. All signals were visually checked by an expert, and artifact-free periods were manually selected and further analyzed.

Feedback based on the activity recorded by the C3 electrode was provided in a visual and auditory form. During training, participants were asked to control images displayed on the computer screen so that the displayed airplane kept flying all the time. The airplane was in motion while meeting the following conditions: amplitudes of the theta (4–7.5 Hz) and beta2 (20–30 Hz) bands remained below the established threshold, and the amplitudes of SMR (12–15 Hz) and beta1 (13–20 Hz) were maintained above the established threshold. Effective movement of the airplane was accompanied by an acoustic reinforcing signal.

2.4. Visual Reaction Time Tests

The impact of neurofeedback training on the visual reaction speed of judo athletes was verified using selected samples from the Vienna Test System (VTS). The Reaction Time (RT) test was used, allowing the precise determination of the athlete's reaction time to the thousandth of a second. The test measured how quickly the athlete could react to the appearance of a stimulus as well as what the quality of the reaction was in situations with multiple stimuli requiring selection and while maintaining reaction time. The test allowed the measurement of simple and complex reaction times. The test was performed using a reaction panel – one of the reaction devices of the Vienna Test System. Tests were conducted in the morning, under conditions conducive to focusing attention on tasks. All tests were repeated twice with a 5-minute interval, with the better results taken for further analysis. The participant's task was to react as quickly as possible to simultaneous visual and acoustic signals (complex reaction) or only visual (simple reaction) by pressing a button on the reaction panel when a yellow light appeared on the screen. The test measured the indicator – average reaction time (MRT) – calculated from the appearance of the relevant stimulus to the moment the finger was lifted from the waiting button. The obtained result was the reaction time.

2.5. Statistical analysis

The normality of the distribution of variables was checked with the Shapiro-Wilk test. Levene's test of homogeneity of variances was used to verify the homogeneity of variables and determine statistical tools. The results of the conducted tests clearly indicated that the variables had a normal distribution or a distribution close to normal ($p>0.05$). The examined homogeneity of variance with Levene's test in groups before training showed no similarities, i.e., homogeneity for all variables. Variable values in both groups after training in the Levene's test were also homogeneous.

To answer the hypotheses regarding testing for no differences between the means in simple and complex reaction time tests before and after EEG-biofeedback training, an analysis of variance (ANOVA) was applied. In the first part of the study, ANOVA was used to determine significant differences between the tested simple reaction time variables concerning groups after individual biofeedback session cycles. In the next step, using the same analysis, differences in the experimental group were examined in the context of both reaction times, taking into account the periods before and after the cycles.

In the final third stage of the study, regression models were built to determine the most significant predictors for each cycle, considering both reaction times. The relationships between the dependent variable (visual reaction time) and other analyzed variables (Theta and Beta values) were estimated using single-factor stepwise ridge regression analysis.

After simplification, the biometric regression model received the following form (equation (1)): $Y = F(x\_1, \ldots, x\_k; a\_1, \ldots, a\_p) + \varepsilon = F(x,a) + \varepsilon$ (1) where: x_j–determinant variable ($x = |x\_1, \ldots, x\_k|\ T$), a_j–parameter ($a = |a\_1, \ldots, a\_p|\ T$), ε–random component (also known as random factor or measurement error).

In summary, additional statistical data analysis was performed using the Statistica program (StatSoft-Poland, Statistica 13, Krakow, Poland, version 2022).

3. Results

Table 2 presents the results of the analysis of variance at the level of statistical significance $p < 0.05$, which showed that hypotheses about no differences between the experimental and control groups regarding the values of the tested simple and complex reaction times after EEG biofeedback training sessions could be rejected. However, Tables 3 and 4 present the results of post-hoc tests for the average simple and complex reaction time (VST) between the analyzed groups.

Table 2. ANOVA results for determining significant differences between the tested simple and complex reaction times variables concerning groups after individual biofeedback session cycles.

Variables	F	p
After the 2nd cycle – simple reaction (VST)	15.897	0.006
After the 1st cycle – simple reaction (VST)	41.317	0.002
After the 2nd cycle – complex reaction (VST)	15.262	0.008
After the 1st cycle – complex reaction (VST)	47.788	0.001

Table 3. Tukey's post-hoc test for simple reaction time (VST) after the 1st and 2nd cycles of EEG biofeedback sessions in the control and experimental groups, with $p < 0.05$.

Group	EG	CG
Differential means	0.214 s	0.225 s
simple reaction time EG after the 2nd cycle		0.006
simple reaction time CG after the 2nd cycle	0.006	
Differential means	0.207 s	0.224 s
simple reaction time EG after the 1st cycle		0.002
simple reaction time CG after the 1st cycle	0.002	

Table 4. Tukey's post-hoc test for complex reaction time (VST) after the 1st and 2nd cycles of EEG biofeedback sessions in the control and experimental groups, with $p < 0.05$.

Group	EG	CG
Differential means	0.339 s	0.355 s
complex reaction time EG after the 2nd cycle		0.008
complex reaction time CG after the 2nd cycle	0.008	
Differential means	0.326 s	0.352 s
complex reaction time EG after the 1st cycle		0.001
complex reaction time CG after the 1st cycle	0.001	

After conducting individual cycles of EEG biofeedback training, beneficial changes were observed only in the experimental group. There were statistically significant differences between the control and experimental groups in the results of simple and complex reaction times in selected Vienna Test System samples. Therefore, further analyses focusing on the experimental group to address the research problem.

For the variables of simple and complex reaction times in selected Vienna Test System samples, presented in Table 5, one-way analysis of variance (ANOVA) at the significance level of $p < 0.05$ indicated that the hypotheses of no differences between the values of the studied variables before and after the application of individual cycles of EEG biofeedback could be rejected.

The determined regression models indicating statistically significant predictors of obtained simple and complex reaction times in the examined experimental group of judo athletes during the Vienna Test have taken the form of regression functions and are presented below.

- In the second cycle (2nd cycle Simple reaction time VST): Y1_IIC – SRT-VST = 0.222 – 0.001* mean Theta.

This means that if the value of the mean theta variable increases by one unit, the average score value ((Y1_IIC – SRT-VST) will decrease by 0.001 s. The analysis also showed that the most important predictor for the variable Y1_IIC – SRT-VST was the mean Theta.

- In the second cycle (2nd cycle Complex Reaction Time VST): Y2_IIC - CRT-VST = 0.358 – 0.002* mean Theta.
  This means that if the value of the mean theta variable increases by one unit, the average score value (Y2_IIC – CRZW) will decrease by 0.002 s. The analysis also showed that the most important predictor for the variable Y2_IIC– CRZW was the mean Theta.
- In the first cycle (1st cycle Simple reaction time VST): Y3_IC - SRT-VST = 0.216 – 0.001* mean Theta.
  This means that if the value of the mean theta variable increases by one unit, the average score value (Y3_IC – SRT-VST) will decrease by 0.001 seconds. The analysis also showed that the most important predictor for the variable Y3_IC – SRT-VST was the mean Theta.
- In the first cycle (1st cycle Complex Reaction Time VST): Y4_IC - CRT-VST = 0.336 – 0.002* mean Beta.
  This means that if the value of the mean beta variable increases by one unit, the average score value (Y4_IC – CRT-VST) will decrease by 0.002 seconds. The analysis also showed that the most important predictor for the variable Y4_IC– CRT-VST was the mean Beta.

Table 5. Result of one-way ANOVA to determine the significance of changes in simple and complex reaction times in selected Vienna Test System samples in the experimental group.

Variables	$\bar{x}$ [s]	S [s]	p
	Simple reaction time (VST)		
Before the 2nd cycle	0.223	0.006	0.001
After the 2nd cycle	0.214	0.005	
Before the 1st cycle	0.222	0.006	0.001
After the 1st cycle	0.207	0.004	
	Complex reaction time (VST)		
Before the 2nd cycle	0.353	0.01	0.001
After the 2nd cycle	0.339	0.009	
Before the 1st cycle	0.351	0.011	0.001
After the 1st cycle	0.326	0.006	

4. Discussion

Sporting achievements are the result of a prolonged, individually planned, and comprehensive training process, encompassing the technical-tactical, fitness, and psychological preparation of the athlete. For a sports training system to fulfill its primary purpose – leading to an increase in athletic performance in line with the athlete's real potential – it requires continuous improvement, modification, and expansion of the tools and training methods used. Many athletes and coaches emphasize the significance of the psychological aspect in the athlete's training process, considering it a crucial element necessary for achieving success at the highest level [14]. Proper mental preparation positively influences not only better coping under competitive pressure but also aids in dealing with training challenges, facilitating the maintenance of adequate motivation and heightened concentration despite increasing fatigue. This, in turn, positively impacts training efficiency. However, psychological preparation in sports is often still marginalized or solely focuses on achieving athletes' psychological readiness, with interventions carried out directly before competition. Psychological practices are seldom utilized throughout the entire training process to enhance athletes' training effectiveness [15].

This research aimed to determine the impact of neurofeedback training, especially targeting Beta and Theta waves, on simple and complex reaction times in judo athletes. Itanalyzed the relationship between brain wave activity and reaction skills in a sports context. The study continued previous findings in sports psychology, emphasizing the importance of psychological training, especially regarding the ability to maintain an optimal level of concentration and reaction under pressure. The significance of reaction time in sports, particularly in disciplines like judo, where quick and precise reactions to visual stimuli are crucial for success, was highlighted.

Due to the significant importance of judo athletes' visual reaction time in enhancing their effectiveness during matches, this study aimed to investigate the impact of EEG biofeedback training. The training was based on the reinforcement of fast Beta waves and the inhibition of slow Theta waves, targeting the efficiency of their visual processing. An attempt was also made to develop an optimal EEG biofeedback training, directed towards regulating concentration levels and improving the visual attention of judo athletes, leading to a reduction in their reaction times. There is compelling evidence suggesting that the beta wave frequency correlates with a state of increased visual attention processing [16], which is crucial in decision-making and reaction planning [17]. The authors also point out that beta activity in the motor cortex is associated with achieving faster motor responses to stimuli. Based on these findings, the present study decided to implement the beta1/theta training protocol to enhance the visual reaction speed of judo athletes.

The research was conducted among a selected group of athletes, members of the national team of the Polish Judo Association. The innovation of the applied neurofeedback training lay in its implementation in two cycles, varied in terms of the duration and frequency of individual training sessions. This ensured alternative measurement conditions, allowing the identification of the most favorable configuration. The obtained results were then subjected to a detailed statistical analysis, enabling a precise assessment of the applied training procedures in relation to the reaction times achieved in both research groups.

The study revealed that athletes from the experimental group, as a result of implementing the beta1/theta protocol, statistically significantly improved their simple and complex reaction times after each training cycle. Similar changes were not observed in the control group. This, however, confirms previous scientific findings indicating that athletes can learn to generate specific neuronal brain activity, leading to an increase in their efficiency [18]. It also complements existing analyses regarding the positive impact of various biofeedback training methods on visual perception and the reduction of athletes' reaction times [19].

The obtained results are also consistent with previous reports suggesting that strengthening beta1 wave activity and inhibiting Theta waves over the motor cortex improve processes related to visual attention. Early studies showed that beta band synchronization just before the appearance of a stimulus was the strongest predictor of task execution speed [20]. EEG biofeedback training conducted among two research groups, where the first group reinforced Theta waves and the second inhibited this frequency, demonstrated increased performance in a test task after reducing theta activity. This also proved the possibility of selectively changing the frequency of brain waves [21, 22]. However, a limitation of this study was the small number of training sessions and the lack of monitoring other changes in neuronal activity accompanying the reduction in Theta waves, making it impossible to determine whether this reduction was associated with an increase in alpha, beta, or a combination of both frequencies.

Hanslmayr et al. [23] demonstrated that the perception of stimuli was associated with lower activation in the Alpha band and greater engagement with Beta and Gamma frequencies. It was concluded that based on the analysis of these values, inferences could be made about the subjects' visual attention state [23]. Similar observations were made by recording increased beta activity during the anticipation period before a stimulus [16,24]. Subsequent analyses also confirmed that greater activation in the beta band (especially in parietal areas) before the exposure to a visual stimulus was associated with shorter reaction times [25].

Egner and Gruzelier [24] examined the effectiveness of applying SMR and beta1 protocols in improving perceptual abilities. Participants were divided into three groups – the first group reinforced SMR waves, the second group reinforced beta1 waves, and the third, a control group, did not undergo any intervention. The analysis of the results showed increased perceptual sensitivity in the SMR group and a significant reduction in reaction times in the beta1 group, with no statistically significant differences in the control group [24]. Ghaziri et al. [26], after analyzing the impact of EEG biofeedback training on concentration, also observed increased visual and auditory attention efficiency due to beta1 band stimulation. Moreover, they demonstrated structural changes in white and gray matter as a result of the neurofeedback intervention, providing evidence of its effectiveness [26].

These findings align with the results presented in this study, indicating the positive impact of reinforcing the beta1 band at the C3 point in improving the visual reaction time of judo athletes. They also confirm previous reports suggesting that beta band activation during open eyes in the left hemisphere may be a predictor of training success [27]. EEG biofeedback training based on the beta1 protocol, conducted by Gruzelier et al. [28] at the C3 point, resulted in positive changes such as a reduced number of errors and less variability in reaction times [28]. Similar observations were made in this study, where favorable modifications in the reaction times of judo athletes were achieved after EEG biofeedback training conducted at the C3 point. This reaffirms the effective impact of interventions based on reinforcing beta1 waves in this area concerning the development of athletes' visual attention.

The study used EEG-biofeedback, a method based on self-regulation of brain wave frequencies, especially Beta and Theta waves. The conducted training sessions and their impact on improving simple and complex reaction times were analyzed. It is worth noting that this study focuses on a group of judo athletes with varying skill levels, adding context to the relationship between skill level and training effectiveness. The research aligns with general concepts in neurofeedback, which can be essential in analyzing the results of studies on its effectiveness in sports [29].

In the study investigating the impact of neurofeedback training on the reaction times of judo athletes, attention was drawn to the comprehensive nature of the sports training process. Sporting achievements result from prolonged efforts, which involve not only technical-tactical and fitness preparation but also a significant psychological aspect. There is a widespread belief among athletes and coaches that proper mental preparation is crucial for achieving success at the highest level [14].

Emphasizing the role of psychology in training, the study focused on neurofeedback training, especially on Beta and Theta waves associated with brain activity. The EEG-biofeedback method was employed, enabling self-regulation of brain wave frequencies. The psychological aspect is, therefore, crucial in sports, as also indicated by studies by other authors [1, 2, 3, 4]. Similarly, the issue of the frequency and intensity of biofeedback training, which is associated with fatigue [6, 7].

It is valuable to consider the context related to the skill levels of judo athletes, adding depth to the analysis. The study aimed not only to improve results but also to understand how brain wave activity influences reaction skills in the context of a specific sport, such as judo. It is crucial to note that reaction time is significant in judo, where quick and precise reactions are key to success.

However, while the results are promising, further research is needed, especially considering a larger number of participants and analyzing the long-term effects of training. Additionally, the authors could consider incorporating other factors into the analysis, such as stress levels or fatigue, which may also influence the reaction time.

5. Conclusions

In summary, the study on the impact of EEG-biofeedback training focused on Beta and Theta waves on simple and complex reaction times in judo athletes during the Vienna Test seems promising. The results suggest that neurofeedback training may significantly improve reaction skills in a sports context. However, for a fuller understanding and confirmation of these effects, further well-controlled studies are necessary. Long-term observations and those considering additional factors may provide a more comprehensive picture of the impact of psychological training on athletic achievements.

6. Practical implications

In the context of sports practice, the results of this study have potential implications for coaches, sports psychologists, and judo athletes. It appears that EEG-biofeedback training, focused on regulating Beta and Theta waves, could be an effective tool in improving reaction times. The application of this type of training may be particularly beneficial for sports where a quick reaction to stimuli is crucial, such as judo. Coaches may consider integrating neurofeedback training into training programs to enhance their athletes' psychological effectiveness. However, due to individual differences among athletes, it is essential to tailor the training to the specific needs of each athlete.

7. Study limitations

It is also important to note several limitations of this study. Firstly, the research sample was relatively small, which may impact the overall representativeness of the results. Therefore, these findings should be considered preliminary, and they require confirmation in larger research groups. Secondly, the analysis did not account for other potential factors influencing reaction time, such as fatigue or stress levels. Including these variables in further research could provide a more comprehensive picture, especially considering the physical demands of combat sports.

8. Directions for future research

Based on the results of this study, certain directions for future research are suggested. It would be crucial to expand the research sample, consider different levels of sports proficiency, and analyze the long-term effects of EEG-biofeedback training. Additionally, researchers could contemplate incorporating other forms of psychological training to compare their effectiveness with neurofeedback training. Comparing different methods could yield valuable insights into optimal strategies for enhancing athletes' reaction skills.

Finally, further studies should also take into account practical aspects of implementing neurofeedback training into training programs, such as equipment availability and training time requirements. Ultimately, a holistic approach to the psychological preparation of athletes requires consideration of various effective strategies, each tailored to athletes' individual needs.

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