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Optimizing visual processing efficiency using neurofeedback training in judo athletes

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Authors' Contribution:
- **A** Study Design
- **B** Data Collection
- **C** Statistical Analysis
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Abstract

Background and Study Aim: Training using the EEG-NFB (electroencephalographic neurofeedback) technique has recently become more and more popular as an innovative method. The aim of this study was knowledge about the effect of the EEG-NFB training protocol on the reaction speed of judo athletes and to determine the optimal duration and frequency of training sessions directed at the improvement reaction speed in combat sport athletes.

Material and Methods: The study examined 12 male athletes from the national team of the Polish Judo Association. Participants were divided into the experimental (EG, n = 6) and the control group (CG, n = 6). The NFB training protocol was performed and recorded using a Biograf Infiniti 6.0 software and the 5-channel ProComp5 decoding device with an EEG sensor. The effect of NFB training was examined by computer-based simple and complex reaction tests and selected tests of the Vienna Test System (VST).

Results: One-way ANOVA showed statistically significant differences between the CG and the EG in theta and beta values after the first and the second cycle of training. There were statistically significant differences between the CG and the EG in the results of reaction speed tests after individual cycles of training.

Conclusions: The highest reduction in complex reaction time was obtained after the first training cycle, when training was performed every second day and the highest reduction in simple reaction time was obtained after the second training cycle, when training was performed every day. In both cycle training lasted four minutes.

Key words: Biofeedback • combat sport • complex reaction • EEG • simple reaction • speed reaction

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

Ethical approval: The study was approved by the Bioethics Committee of the Academy of Physical Education in Katowice (Poland)

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EEG – non-invasive diagnostic method for testing bioelectrical brain function using an electroencephalograph.

Theta waves (3 - 8 HZ) – reduce stress, arouses intuition and other extrasensory perceptions of skills.

Beta waves (12 - 38 HZ) – dominate when we are alert, engaged in problem solving, decision making, or focused mental activity.

TBR – Tree-Based Routing.

Training session – *noun* a period of time during which an athlete trains, either alone, with a trainer or with their team [22].

INTRODUCTION

Training using the electroencephalographic neurofeedback (EEG-NFB) technique has recently become more and more popular as a method of improving attention [1], concentration [2], creativity [3], postural control [4] and reducing reaction time [5]. As an innovative method, EEG-NFB training has been widely used in sports such as speed skating [6], archery, shooting and golf [3, 7, 8], gymnastics [9], canoeing/kayaking [10] or dancing [11].

Numerous research has shown a reduction in reaction time following EEG-NFB training and a positive effect on eye-hand coordination, concentration and attention in athletes [5, 11, 12]. The research demonstrated an improvement in reaction time after NFB training with the use of TBR protocol, but experiments that did not confirm such training effects were also conducted [13]. The lack of clearly defined variables of the EEG-NFB training methodology may be of great significance. Despite the enormous potential of the EEG-NFB in sport, it remains unclear which number and what frequency of training sessions allow for the greatest progress of results. Furthermore, no training protocols have been developed to clearly confirm the effectiveness of the intervention in mastering of particular skills of players that determine their sports success.

The aim of this study was knowledge about the effect of the EEG-NFB training protocol on the reaction speed of judo athletes and to determine the optimal duration and frequency of training sessions directed at the improvement reaction speed in combat sport athletes.

MATERIAL AND METHODS

Study participants

The study examined 12 male athletes from the national team of the Polish Judo Association aged 22-25 years. The total number of study participants (12) was selected purposefully from the members of the national team of the southern region of Poland. The athletes were randomly divided into two subgroups: experimental (n = 6) and control (n = 6). All participants were informed about the objectives and procedures of the research, and about the possibility of withdrawal from the research at any stage of its duration. All participants were healthy and refrained from using drugs, alcohol and stimulants (caffeine, energy drinks) 12 hours before each test and training session.

The research protocol was approved by the Bioethics Committee of the Academy of Physical Education in Katowice.

Research procedure

The tests were conducted in two cycles, differentiated by frequency, but with the same duration of the EEG biofeedback sessions, both in the control and experimental groups.

The first cycle of the research included 15 training sessions held every second day. The duration of the training session was 4 minutes and it was a modification of Dupee's training [14]. The second series of the research, which took place after a four-week break, was a modification of the Thompson's training program [15], characterized by a higher frequency of meetings (every day), whereas the duration of a single training session was maintained at 4 minutes. During each session, the percentage of time above the threshold was monitored, which was shifted up or down respectively for the amplified and inhibited wave, so that the level of difficulty of training was optimal and adjusted 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 narrow attention of athletes.

Before the beginning of the first training cycle, and after the completion of each subsequent cycles, simple and complex reaction time was evaluated in both study groups. The control group followed the same pattern as the experimental group and was characterized by the same timetable, duration and frequency of EEG biofeedback training sessions. The procedure of preparation for the 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 patterns of brain waves produced by the participant.

EEG biofeedback training

The neurofeedback training was performed using Biograf Infiniti 6.0 software and the 5-channel ProComp5 decoding device with an EEG sensor. The quality of the device was confirmed by ISO and CE certificates. Before the EEG signal was recorded, the electrode impedance level and the inter-electrode levels were checked each time using a built-in impedance sensor. In order to start the diagnosis and EEG biofeedback training, it was necessary to achieve an impedance level below 5 kΩ and measurements between electrodes differing from each other by no more than 1 kΩ.

Each training session in each cycle was preceded by a 3-minute one-channel diagnosis. During this time, the participants were asked to perform the following tasks: to remain seated with eyes open for one minute, to remain seated with the eyes closed for one minute, to remain seated with the eyes open with the additional activation task in the form of a countdown every 7 from 100. During the diagnosis, the reference electrode was fixed to the left earlobe, the grounding electrode was fixed to the right earlobe and the active electrode was fixed at point Cz, according to the international system 10-20. During the EEG biofeedback training, the active electrode was fixed at point C3, which enabled the main goal of the training to be achieved (development of the ability to maintain an optimal balance between the fast (beta) and slow (theta) wave activity. 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 level of training difficulty for each athlete.

The recorded signals were filtered between 2 and 40 Hz. All signals were visually checked by an expert and the periods without artefacts were selected manually and further analysed.

The feedback signal based on the activity recorded from the C3 electrode was provided in visual and auditory form. During the training, the participants were asked to perform a task that consisted in controlling the images displayed on the computer screen so that the plane shown was flying all the time. The plane was in motion when the appropriate conditions were met at the same time: theta (4-7.5 Hz) and beta2 band amplitudes (20-30 Hz) were maintained below a set threshold and sensorimotor rhythm (SMR) (12-15 Hz) and beta1 amplitudes (13-20 Hz) maintained above a set threshold. The effective movement of the aircraft was accompanied by an acoustic amplifying signal.

Visual reaction speed tests

The effect of neurofeedback training on visual reaction speed of judo athletes was verified by means of computer-based simple and complex reaction tests and selected samples of the Vienna Test System (VTS). The tests were carried out in the morning, under favourable conditions for focusing attention on the tasks. All tests were repeated twice at 5-minute intervals, with better results taken for further analysis.

The computer test of simple reaction to visual stimuli consisted of the fastest possible pressing of a specific key on the keyboard with the right or left hand at the moment when a bright square appeared on the screen. The task of complex reaction time required the fastest possible pressing of a key on the keyboard corresponding to the position of a square appearing on the monitor, different in case of its location on the right, left or central point of the screen. In both tests, the signal was displayed 10 times at 2-6 s intervals. The evaluated time period began from the moment the stimulus appeared until the key was pressed, with the accuracy of 0.01 s.

A evaluation of simple reaction speed (RG), as a component of the Vienna Test System was used to test simple reaction to visual stimuli. The study participant was to move his or her hand from the so-called “rest key” as fast as possible to press the “reaction key” when the yellow diode was lit. Based on the data received, the program calculated the median of reaction speed, reaction time and simple reaction time in ms. The complex reaction speed was tested by means of a decision tester (DG), where the test required the fastest possible pressing of the appropriate key (depending on the colour of the lighting diode) when the stimulus appeared. The program indicated the number of all correct reactions, abnormal reactions, the average reaction speed and the standard deviation of the average reaction speed. The signal was displayed 15 times.

Statistical methods

We used the following descriptive statistics to evaluate the level of analysed variables: arithmetic mean, standard deviation and coefficient of variation.

Homogeneity and normality of distribution were verified using the Shapiro–Wilk test. The differences between the experimental and control groups were analysed using ANOVA variance. Intragroup and intergroup differences were tested by the post-hoc Tukey’s test for equal sample sizes

(N). The significance level was set at p<0.05. The above calculations were made using Statistica software (StatSoft Polska Sp. z o.o.) and Excel spreadsheet of Microsoft Office (Microsoft Poland).

RESULTS

One-way ANOVA with repeatable measures showed (at p<0.05) that the hypothesis of homogeneity of variance between the values of the tested variables of simple and complex reaction times could not be rejected in relation to the experimental and control group. The variables were homogeneous. Therefore, no statistically significant differences between CG and EG were observed in the results of the computer and Vienna reaction speed tests before the training sessions.

A one-way ANOVA with repeated measures showed (at p<0.05) that the hypothesis of homogeneity of variance between the values of the tested variables determining the values of theta and beta waves following successive biofeedback sessions could be rejected. Statistically significant differences were observed between the CG and EG in theta and beta values after each training cycle. There were no differences in the theta values after the first training cycle (Table 1).

The one-way ANOVA (at p<0.05) showed that the hypothesis of homogeneity of variance for CG and EG between the values of the variables of simple reaction speed and complex reaction speed after biofeedback sessions could be rejected. The variables were not homogeneous. Statistically significant differences between CG and EG were observed in the results of the computer and Vienna speed of reaction tests after particular training cycles, both in simple reaction tests and complex reaction tests (Table 2).

For variables of the simple reaction speed in the computer test and the Vienna test, the analysis using the Student's t-test at the level of statistical significance p<0.05 showed that the hypothesis of homogeneity of variance between the tested variables before and after the use of individual biofeedback training cycles could be rejected (Figure 1).

Similarly, for variables of the complex reaction speed in the computer test and the Vienna test, the analysis with the Student's t-test showed that the hypothesis of homogeneity of variance between the values of the tested variables before and after the application of particular biofeedback training cycles could be rejected (Figure 2).

Table 1. The results of ANOVA used to determine significant differences between the tested theta and beta values with respect to each training cycle.

Variables	Cycle	F	p
Theta	I	3.188	0.088
Beta		5.116	**0.034**
Theta	II	6.034	**0.022**
Beta		9.081	**0.006**

Table 2. The results of the analysis of variance (ANOVA) used to determine significant differences between the variables of simple and complex reaction speed following biofeedback training sessions.

Variable	Test-	After I training cycle		After II training cycle	
		F	p	F	P
Simple reaction speed	Computer Test	6.77	0.016	53.95	0.001
	Vienna Test	5.878	0.024	16.105	0.001
Complex reaction speed	Computer Test	24.536	0.001	4.953	0.037
	Vienna Test	25.706	0.004	6.239	0.020

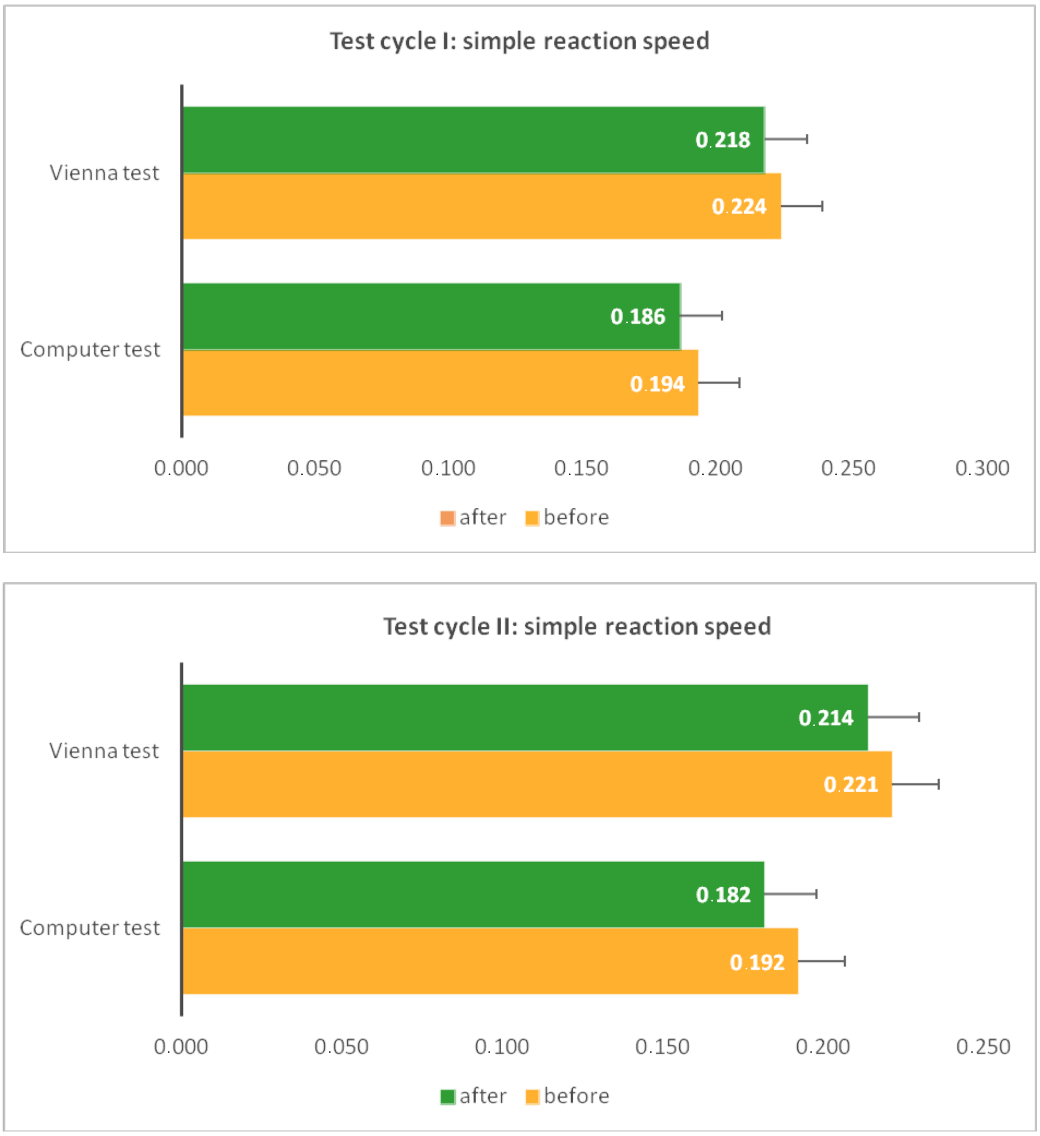

Figure 1. Graphical presentation of the results of simple reaction speed before and after the first and second cycle of biofeedback training.

DISCUSSION

As shown by numerous scientific reports, the introduction of modern training techniques for athletes, such as the EEG-NFB training, can significantly contribute to the development of new tools used in the field of competitive sport. Previous studies have indicated that athletes can learn from EEG-NFB training to generate and maintain specific brain neural activity associated with their increased performance [16]. Despite the enormous potential of the use of the EEG-NFB method in sport, it remains unclear which number and what frequency of training sessions allow for optimal results.

Due to the importance of visual reaction speed among judo athletes in the context of increasing their effectiveness during a combat, the aim of this study was to determine the optimal frequency of EEG-NFB training sessions, based on the amplification of beta fast waves and inhibition of theta slow waves, on the efficiency of their visual processing.

The study participants were a group of selected athletes from the Polish national judo team. Due to the theta/beta1 intervention, the athletes from the experimental group achieved a statistically significant improvement in simple reaction

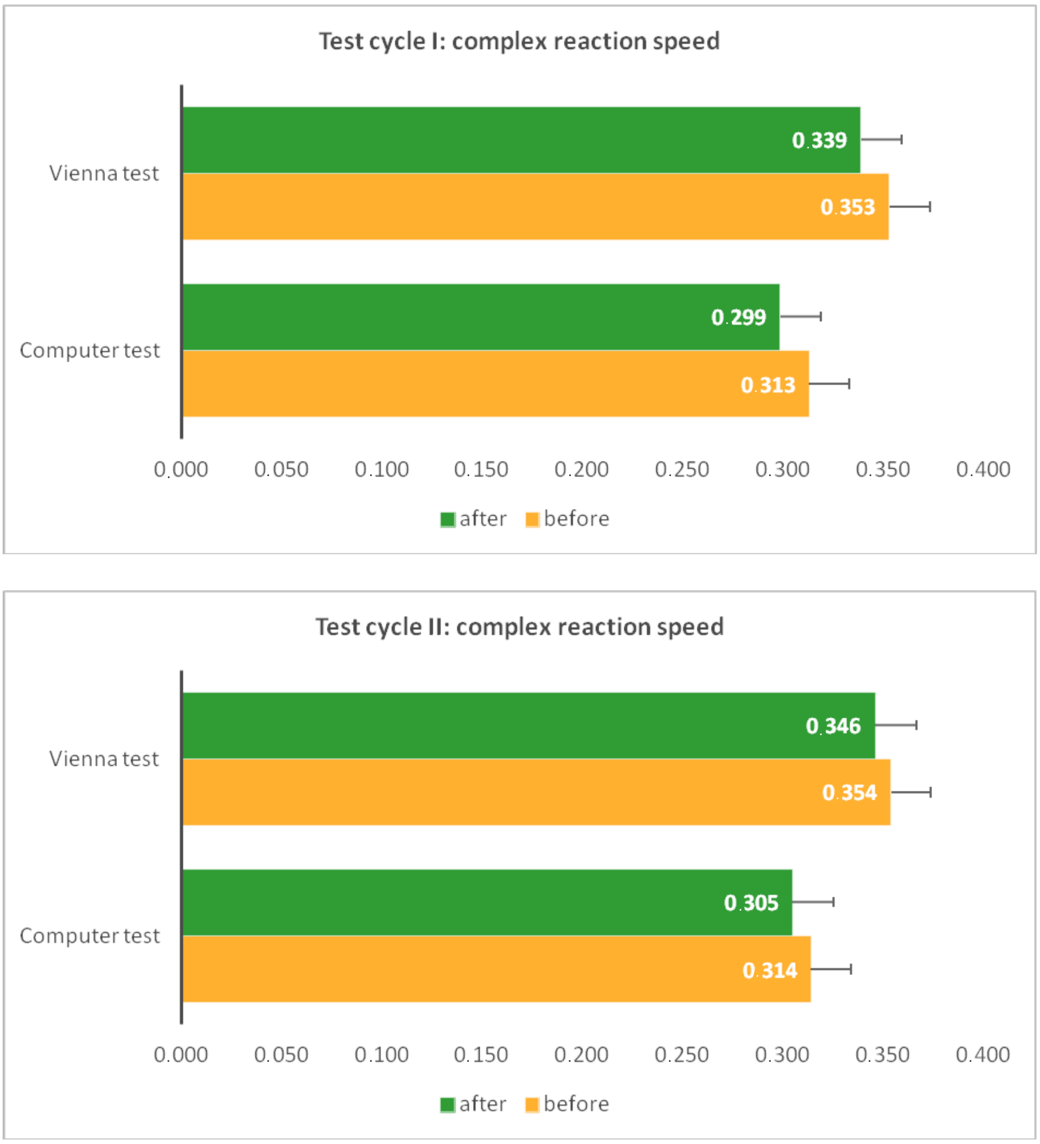

Figure 2 Graphical presentation of the differences in results of complex reaction speed before and after the first and second cycle of biofeedback training.

time and complex reaction time after training cycle. No similar changes were observed in the control group. The results of this study suggest that judo athletes can learn to control brain wave activity during EEG-NFB training, which in turn facilitates attention and improves reaction time [17].

The obtained results are also consistent with the current scientific reports suggesting that as a result of amplification of beta1 waves activity and inhibition of theta waves over the motor cortex, the visual attention processes are improved. The research by Kaminski et al. [18] showed that higher activation in the beta band before the exposure to the visual stimulus was associated with shorter reaction times.

Furthermore, Egner et al. [19] used SMR and beta1 protocols in the context of improving perceptual abilities and demonstrated increased perceptual sensitivity in the SMR group and significant shortening of reaction times in the beta1 group. No statistically significant differences were observed in the control group.

Subsequent analyses carried out by Egner and Gruzelier [20] using the beta1 protocol showed positive changes in the form of a reduced number of errors and smaller variation in reaction times.

However, issues related to the optimal frequency and duration of EEG biofeedback training sessions to achieve the training objectives are still under investigation. Previous findings provide contradictory results.

Doppelmayr and Weber [13] used two protocols (SMR and TBR) to improve spatial abilities, creativeness and reaction time. It was demonstrated that training participants were unable to change the TBR values or separately analysed theta or beta frequency bands within 30 days of training. In a study by Vernon et al. [21], it was also found that participants were unable to modify theta waves with positive changes in SMR activity after only eight training sessions.

The analysis of results revealed a statistically significant improvement in simple and complex reaction time following each training cycle in judo athletes, which translated into an improvement of coordination and the mechanisms of visual information processing. The study showed statistically significant differences in the activity of particular brain wave frequencies. There was no difference only in the theta values after the first training cycle, which may suggest that more training sessions are needed to achieve the desired changes in the values of theta waves in healthy people.

The differences in the duration, frequency and the number of training sessions required to achieve the training objectives are primarily due to individual differences, thus the optimal solution is to develop personalized EEG-NFB interventions for each athlete. Due to a large number of respondents and detailed statistical calculations included in this paper, all analyses were carried out based on the average values of the results. This allowed for a rough determination of the optimal (in terms of duration and frequency of training sessions) EEG-NFB training, leading to improved reaction times of judokas.

CONCLUSIONS

In our study performed in a group of judo athletes, the highest reduction in simple reaction time was obtained after the second training cycle, when training was performed every day and lasted four minutes and the highest reduction in complex reaction time was obtained after the first training cycle, when training was performed every second day and lasted four minutes. The duration of training is the same as the duration of the fight of judo athletes where it was easier to keep full attention.

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