Original Article

doi: 10.16926/par.2024.12.22

The influence of EEG-biofeedback training and Beta waves in normoxia and normobaric hypoxia on the bench press in judo athletes

Magdalena Prończuk [1ABCDE], Dariusz Skalski [2ADE], Marcin Zak [3ABCD], Joanna Motowidło [3ABC], Jarosław Markowski [4ABDE], Jan Pilch [5ADE], Maciej Kostrzewa [3ABDE], Anatolij Tsos [6DE], Adam Maszczyk [3ABCDE]

[1] Faculty of Physical Culture, Gdańsk University of Physical Education and Sport, Poland
[2] University of Applied Sciences in Wałcz
[3] Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland
[4] Department of Laryngology, Faculty of Medical Sciences, Medical University of Silesia in Katowice, Poland
[5] Department of Physiological and Medical Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland
[6] Institute of Physical Culture, Jan Dlugosz University in Częstochowa, Poland

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

Abstract: The aim of this study was to assess the effect of EEG-Biofeedback training in normoxic and normobaric hypoxic conditions on bench press improving in elite judo athletes. The study included 20 male elite judo athletes. 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 research was carried out over two cycles that differed in the external conditions of EEG biofeedback trainings for both the control and experimental groups. The experimental group underwent training under simulated hypoxic conditions The training sessions for the experimental group were conducted at a simulated altitude of 3000m above sea level. Each cycle of the study comprised of 15 training sessions. The control group's study followed the same frequency, and duration of EEG biofeedback training sessions, and demonstrated an identical pattern to that of the experimental group, but in normoxia conditions. In the discussed cycle conducted in hypoxia, a clear upward dynamics of Beta wave values with a growing trend from session 14 was observed. In normoxia, the variability in the EG group had a significantly less dynamic course. In hypoxia, a clear upward dynamics of the achieved PP values with a growing trend from measurement 14 was observed. In normoxia, the discussed measurement cycle conducted in the CG group showed a lesser upward dynamics of achieved PP values with a growing trend from measurement 10. The overall conclusion from these analyses suggests that EEG biofeedback training in hypoxic conditions may have a beneficial impact on brain activity and improvement in muscle strength and power. These results may be of significant importance for sports training and rehabilitation, especially for individuals engaged in sports disciplines requiring physical exertion in low oxygen environments.

Keywords: EEG training, bench press tests, Beta wave, ROM, peak velocity

Corresponding author: Adam Maszczyk, email: a.maszczyk@awf.katowice.pl

Recevied: 27.03.2024; Accepted: 14.05.2024; Published online: 3.07.2024

Citation: Prończuk M, Skalski D, Zak M, Motowidło J, Markowski J, Pilch J, Kostrzewa M, Tsos A, Maszczyk A. The influence of EEG-biofeedback training and Beta waves in normoxia and normobaric hypoxia on the bench press in judo athletes. Phys Act Rev 2024; 12(2): 65-77. doi: 10.16926/par.2024.12.22

INTRODUCTION

Research on the effects of EEG-biofeedback training, specifically focusing on Beta waves, and its effects under normoxic and normobaric hypoxic conditions on bench press performance in judo athletes is relatively limited, but there are several important aspects that can be understood from general research on about neurofeedback, brain control and the impact of the environment on the level of athletes' performance. Firstly, as has already been documented in research, EEG-biofeedback training, especially focusing on Beta waves, can help to improve concentration and focus. For judo athletes who need to maintain focus and concentration during competition, neurofeedback training can help maintain a high level of attention. Trying to combine EEG training with bench pressing will help investigate this relationship. [1-5]. Moreover, studies suggest that EEG-biofeedback training may help regulate brain activity, which can be particularly important in hypoxic conditions where reduced oxygen supply may affect cognitive functions. Judo athletes training in hypoxic conditions could benefit from better regulation of brain activity, which would impact the effectiveness of their strength training [1,6].

In judo training, the ability to cope with stress and psychological pressure is crucial. EEG-biofeedback training can help increase stress tolerance, which can be beneficial both during training and competition [2]. In hypoxic conditions, where oxygen content is lower, brain control may be important for optimizing physical performance. Neurofeedback training can help judo athletes adapt to these conditions, improving cognitive functions and control over physical processes [1]. Additionally, EEG-biofeedback training can provide individual feedback on brain activity for each athlete, allowing for better adaptation of training to their individual needs and psychological characteristics [1,3,4,7-9]. EEG biofeedback training, based on measuring and regulating brain electrical activity, can be tailored to various goals, including movement development. Regarding bench press, some potential benefits from this type of neurofeedback training can be observed [6,7]. What is important, to develop athletes' strength, it is necessary to appropriately adjust training parameters, including brainwave frequencies being investigated. Beta waves are associated with mental activity, concentration, and motor actions, which are relevant during strength exercises. Training based on Beta waves can also help increase motor readiness and improve motor coordination [10-14]. Theta waves, on the other hand, are associated with deep relaxation and sleep. In movement training, they can be useful in the context of regeneration and rest after intense physical exertion. It is worth noting that the effectiveness of EEG biofeedback training in developing sensation or movement depends on the individual needs and thresholds of the client as well as the skills of the specialist conducting the training.

To increase concentration and mental engagement, the usual goal in EEG biofeedback training is to increase the level of Beta waves. By increasing the level of Beta waves, attention focusing ability can be improved, performance in tasks requiring concentration can be enhanced, engagement in activities can be increased, and effectively responding to mental challenges can be achieved. Examining Theta wave levels in strength training is not typical because Theta waves are usually associated with deep relaxation and more passive states of mind. Through applying mental training related to concentration, motivation, muscle control, and movement technique development, Theta waves are mentioned for a simple reason. Very often training is based on the theta/beta protocol. However, looking at the orientation of training towards specific goals in this case improving strength skills during bench press, the focus is on biofeedback training and a protocol aimed at increasing the level of Beta waves. This also makes sense for the central nervous system (CNS) which is responsible for processing information that constitutes specific feedback. Nerve connections that are frequently used develop, while those that are less utilized are "pruned" to enable optimal CNS functioning. The neuromuscular system employs two strategies to regulate the force generated during a specific task. One involves recruiting motor units, and the other involves encoding (frequency) of electrical impulses or action potentials generated down the motor neuron to the muscle fiber it innervates [3,12,15].

In advanced judo training, excessive training loads cause numerous micro-injuries that require adaptations in the neuromuscular system during resistance exercises. In symmetrical exercises, such as bench press, these changes may occur between the left and right limbs, leading to incomplete assessment from one side of the body, resulting in erroneous conclusions. This is associated with specific control centers in the brain. Proper coordination of information flow and its optimization positively influences task performance, but this also depends on the external environment [16-20].

Thus, the aim of this study was to assess the effect of EEG-Biofeedback training in normoxic and normobaric hypoxic conditions on bench press improving in elite judo athletes.

MATERIAL AND METHODS

Participants

The study included 20 male elite judo athletes. 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. All subjects had recent medical examinations confirming their ability to perform intense physical exertion (Experience [years] 10.8 ± 4.7; 1RM [kg] 128 ± 21; range of motion [cm] 35 ± 3.7).

The subjects were randomly divided into an experimental group (H-group; n = 10; age 19.6 ±1.4 years; height 183.2 ±3.1 cm; body weight 79.6 ±6.9 kg) in normobaric hypoxia EEG-BF training or to the control group (N-group; n = 10; age 20.1 ±1.6 years; body height 182.1 ±2.5 cm; body weight 78.1 ±6.1 kg) in normoxia EEG-BF training.

Before participation in the study, all subjects were informed of the purpose of the study and gave written consent to participate. Participants were also informed that they could withdraw from further participation in the experiment at any time without giving a reason. The research project was conducted under grants NRSA303953 and NRSA404054 and approved by the Bioethics Committee for Scientific Research at the Academy of Physical Education in Katowice. The research was conducted at the Human Psychomotor Laboratory and Hypoxia Laboratory of the Jerzy Kukuczka Academy of Physical Education in Katowice.

The general procedures

The research was carried out over two cycles that differed in the external conditions of EEG biofeedback trainings for both the control and experimental groups. The experimental group underwent training under simulated hypoxic conditions in a laboratory fitted with a normobaric hypoxia generation system (LOS-HYP1/3NU, Lowoxygen Systems, Germany). The training sessions for the experimental group were conducted at a simulated altitude of 3000m above sea level ($FiO2$ = 14.7%). Each cycle of the study comprised of 15 training sessions. The training sessions lasted for 9 minutes, comprising of 2 sets of 4 minutes each with a 1-minute break in between. During the initial phase, the participants underwent EEG biofeedback training every other day. In the subsequent phase, the frequency remained the same as before, but the training was conducted under normobaric hypoxic conditions. Following this, the frequency of sessions increased, with the third cycle involving daily training under normoxic conditions, and the fourth cycle under hypoxic conditions. The experimental group underwent beta training as a fundamental protocol to enhance concentration and achieve the athletes' narrow attention in normobaric hypoxia conditions. The control group's study followed the same frequency, and duration of EEG biofeedback training sessions, and demonstrated an identical pattern to that of the experimental group, but in normoxia conditions. The preparation process was identical for both groups.

EEG-BF training

Biofeedback training was conducted through the use of the EEG DigiTrack software, which was fitted with the ExG-32 head. The device quality was verified through the acquisition of an ISO certificate and a CE medical certificate. Before EEG recording, the impedance levels of the electrodes as well as the inter-electrode were checked using the built-in impedance sensor on each occasion.

To initiate the diagnosis and NFB training, the requirement was to achieve an impedance level below 5 kΩ and a difference of no more than 1 kΩ between electrodes. Each training session in the individual cycles began with a 3-minute single-channel EEG diagnosis using three reference connections. During this phase, the subject was instructed to perform specific tasks, including sitting with eyes open for one minute, sitting with eyes closed for one minute, and sitting with eyes open while counting backwards by 7 from 100.

For the diagnosis, the reference electrode was placed on the left ear lobe, grounding on the right, and the active electrode at point Cz, following the international 10-20 system. During NFB training, the active electrode was placed at point C3 and C4, which allowed the main training objective to be achieved. This objective was to shape the ability of the athletes to maintain an optimal balance of beta1 waves, which are responsible for achieving a state of concentration and focus.

Throughout each NFB session, the percentage of time spent above the threshold was monitored. This measurement served as the primary indicator of the subject's progress and allowed for the optimization of the training difficulty level for each athlete.

During the NFB training sessions, real-time feedback was provided to the athletes based on their brainwave activity. The main focus was on shaping their ability to enhance the balance between beta and theta waves to achieve an optimal state of concentration and focus. The software allowed the athletes to visualize their brainwave patterns on a computer screen during the training.

The NFB training consisted of multiple cycles, and each cycle comprised several sessions. In the experimental group, each cycle included 15 training sessions, followed by a four-week break, as mentioned earlier. The duration of the training sessions varied across successive rounds of studies, with sessions lasting 9 minutes, as per the modification of Dupee's training method [21]. Throughout the NFB training, the researchers closely monitored the percentage of time that the athletes spent above the predetermined threshold for beta and theta waves. This measure served as the primary indicator of their progress and allowed the researchers to adjust the difficulty level of the training for each individual, ensuring that the training was tailored to their specific needs and responses.

The goal of the NFB training in the experimental group was to increase concentration and achieve what is known as "narrow attention" in athletes. This enhanced the ability to focus and maintain the optimal balance of brainwave activity what could potentially lead to improved athletic performance.

In the control group, the NFB training sessions followed the same schedule, duration, and frequency as the experimental group, the same protocol.

Before commencing the first session and after completing the all, both research groups underwent bench press tests. These tests were conducted to assess any changes in bench press performance resulting from the NFB training in both the experimental and control groups.

Overall, the EEG biofeedback training with the beta1 protocol aimed to explore the potential benefits of this specific training method for athletes' concentration and focus [3-5,22-24]. The results of the study could have implications for optimizing athletic training programs and enhancing athletes' mental and cognitive capabilities.

Bench press tests

All participants underwent training sessions with a standard barbell during bench press, which were conducted using a randomized crossover design. This setup aimed to investigate the effects of individual bench press sessions on subsequent and delayed bench press throw performance. All participants took part in one familiarization session and two experimental sessions. One of these sessions included a one-repetition maximum test during flat bench press (1RM test). The experimental procedures consisted of 2 sets of bench press exercise with a load equal to 70% of the bench press one-repetition maximum (1RM) to volitional failure, using a standard barbell (Figure 1). The 1RM tests were conducted 72 hours apart, while the bench press sessions were executed one week apart. To prevent fatigue, participants were instructed to avoid additional resistance exercise within 72 hours of testing.

The first session aimed to determine the 1RM using a standard barbell. Each experimental session began with a standard warm-up [25]. Then, using a standard barbell, participants performed the 1RM bench press test. They completed a single repetition, without pausing, with a constant tempo of the eccentric phase of the movement (2 s) and a volitional tempo of the concentric phase of the lift [26]. Hand positioning on the bar was similar throughout each trial and was placed at 150% of the participant's bi-acromial distance [27]. The test comprised three attempts. The first attempt was set at 80% of the self-reported 1RM, and if successfully lifted, the weight was increased by 2.5 kg to 5 kg in subsequent attempts. Participants were instructed regarding the technical requirements of bench press, including keeping their feet on the floor, hips in contact with the bench, and avoiding bouncing the barbell off the chest. Two experienced spotters were present throughout to ensure safety.

The experimental sets were performed using a standard barbell during bench press sessions. In each session, participants performed 2 sets of bench press exercise to volitional failure, loaded at 70% of their 1RM, in a randomized order. The movement tempo during bench press was identical to that during the 1RM test, with a 5-minute rest interval introduced between each set. To prevent circadian fluctuations, all tests were conducted at the same time of day (12 and 3 p.m), with a 96-hour break between them. As movement velocity has previously been demonstrated as an indicator of neuromuscular fatigue [28], changes in barbell velocity during bench press throws (BPT) were evaluated to determine how each bench press session affected the fatigue progression. For this purpose, prior to and 1 hour after each session, all participants performed a single set of two repetitions of BPT on the Smith machine at maximal velocity against a load equal to 30% of the 1RM of the standard barbell bench press. Additionally, mean velocity, barbell displacement, and the number of repetitions performed were recorded during each bench press exercise set. Peak velocity was measured during BPT. A Tendo Power Analyzer system (Tendo Sport Machines, Trencin, Slovakia) was used to measure bar velocity and displacement during both bench press exercise and BPT [29].

Statistical analysis

To characterize the structure of the examined variables, basic descriptive statistics were calculated in the form of measures of central tendency (the mean) and measures of variability (the standard deviation). Both results and input data were presented as records in a tabular matrix.

The distributions of the examined variables were verified using the Shapiro-Wilk test for normality. The homogeneity of variances was checked with Levene's test. In summary, all variable variances had a normal distribution with slight left or right deviations, which, however, fell within the normal range. Additionally, the significance level for Mauchly's test was checked. Since the results were statistically insignificant, it indicated the sphericity of variances. The Shapiro-Wilk tests indicated a violation of data distribution for the following variables: the Beta wave value, the number of performed repetitions, range of motion during the bench press, and peak velocity during the bench press throw.

The dynamics of beta wave variability in normoxia and hypoxia during concentration tests were analyzed after consecutive biofeedback sessions, using indices based on fixed and variable time series. To verify the significance of differences between groups, repeated measures analysis of variance (ANOVA) was applied. In the case of significant differences, further analysis was conducted using the Tukey post-hoc test. The F-statistic and significance levels were presented. If the normality was not confirmed, the related-samples Friedman's two-way ANOVA by ranks was used to investigate differences in training variables during the bench presses and their influence on the bench press throw performance. Standardized effect sizes were used to express the size of mean differences. Thresholds for qualitative descriptors of Hedges g were interpreted as small, medium, and large at ≤20, 0.21–0.79 and >0.80, respectively [31].

For all analyses, a statistical significance level of $p<0.05$ was adopted. All calculations were performed using the Statistica v.13 software (StatSoft, USA, CA).

RESULTS

EEG training for Beta

Regarding the examined judo athletes, the average dynamics of diagnostic changes in Beta wave values in normoxia and hypoxia, as well as the actual values of growth dynamics in μV, are presented in Figure 1. Constant index was calculated in relation to the baseline constant, and variable index at measurement points in relation to preceding points. The growth index values were provided as percentages.

In the discussed cycle conducted in hypoxia in the EG group, a clear upward dynamics of Beta wave values with a growing trend from session 14 was observed (Figure 1). Decreases in the indices of Beta wave values compared to preceding sessions were noted in sessions 14 (6.5%) and 15 (4.2%). However, overall, following the completion of the EEG training cycle, the Beta wave value was increased by 53.9% compared to session 1 (in session 13, the Beta wave value was increased by 67.1% compared to session 1).

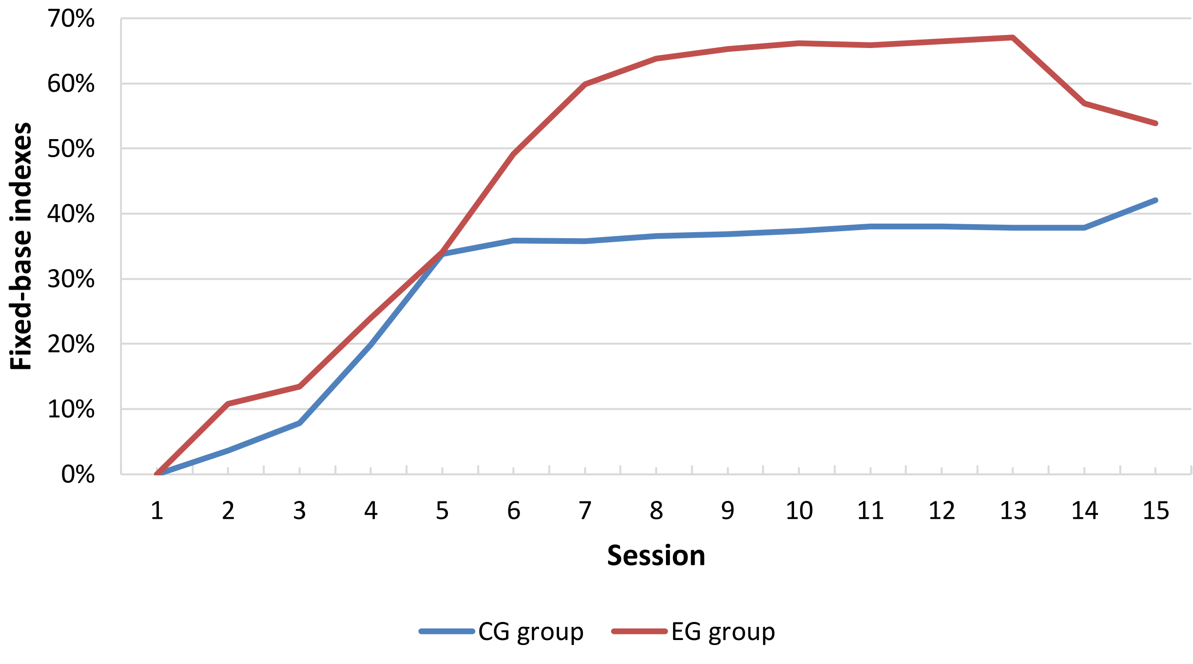

Figure 1. Comparison of the dynamics of diagnostic variability in Beta wave values in the experimental and control groups using fixed-base indexes

In normoxia, the variability in the EG group had a significantly less dynamic course. From session 5, the variability of growth in relation to successive sessions averaged 0.2% (Figure 1). In session 15, the Beta position was increased by 42% compared to session 1. The greatest increases occurred in sessions 2, 4, and 15 compared to preceding sessions (Figure 1).

What is visually evident (Figure 1) has been confirmed in the analysis of variance (ANOVA). The results indicated significant differences in Beta values after the 6 to 13 session, between the EG and CG groups. The post-hoc tests revealed average values differentiating the groups and significantly differences between the EG and CG groups in: session 6 (Differential means (dm): 4.98μV /4.53μV (EG/CG) with p=0.039); session 7 (dm: 5.34 μV /4.52 μV (EG/CG) with p=0.030); session 8 (dm: 5.47 μV /4.55 μV (EG/CG) with p=0.032); session 9 (dm: 5.52 μV /4.56 μV (EG/CG) with p=0.033); session 10 (dm: 5.55 μV /4.57 μV (EG/CG) with p=0.041); session 11 (dm: 5.54 μV /4.60 μV (EG/CG) with p=0.031); session 12 (dm: 5.56 μV /4.60 μV (EG/CG) with p=0.030); session 12 (dm: 5.58 μV /4.59 μV (EG/CG) with p=0.030).

In relation to the examined judo athletes, the average dynamics of changes in bench press performance after successive sessions of EEG-biofeedback training in normoxia and hypoxia were proceeded. The repeated measures analysis of variance (ANOVA) revealed a significantly higher 1RM value after hypoxia EEG trainings than in normoxia (128 ± 21 kg vs. 110 ± 20 kg; $p < 0.001$; ES = 0.40).

Range of Motion

Two-way ANOVA indicated a non-significant interaction (F=0.493; p=0.467; η2=0.062), but a significant main effect of condition (F=12.334; p=0.004; η2=0.536) and set (F=15.413; p=0.001; η2=0.634). The post-hoc comparisons showed significantly greater ROM in bench press after hypoxia EEG trainings than in normoxia (p=0.006; η2=0.545). Moreover, the ROM was significantly greater in the first set compared to the second (p=0.331; η2=0.059) (Figure 2).

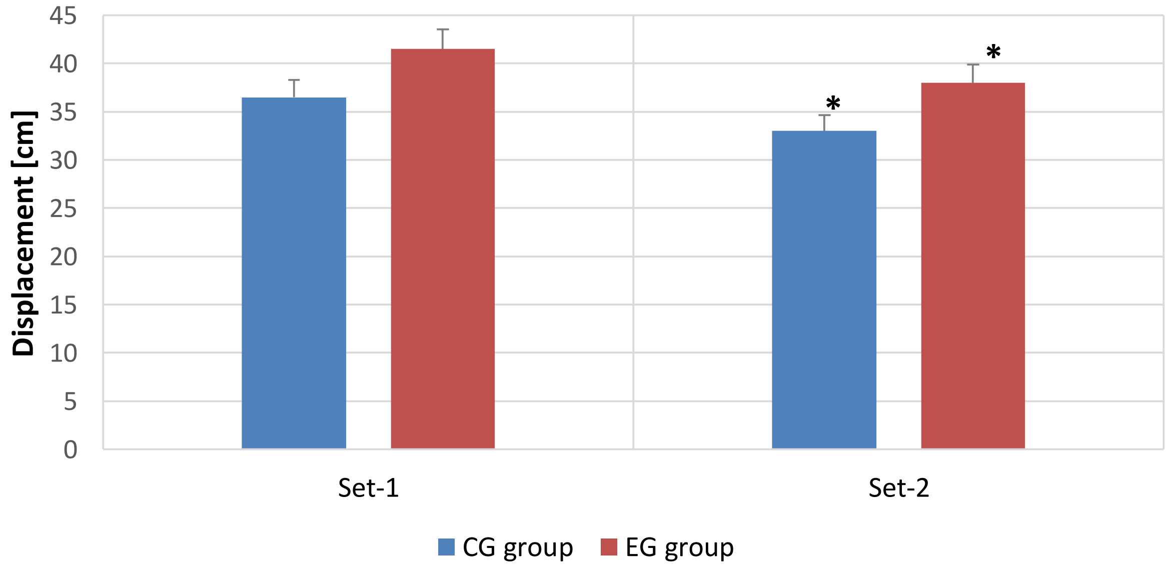

Figure 2. Differences in the ROM between st 1 and set 2 of bench press in EG and CG groups. (*significant difference in comparison to the first set)

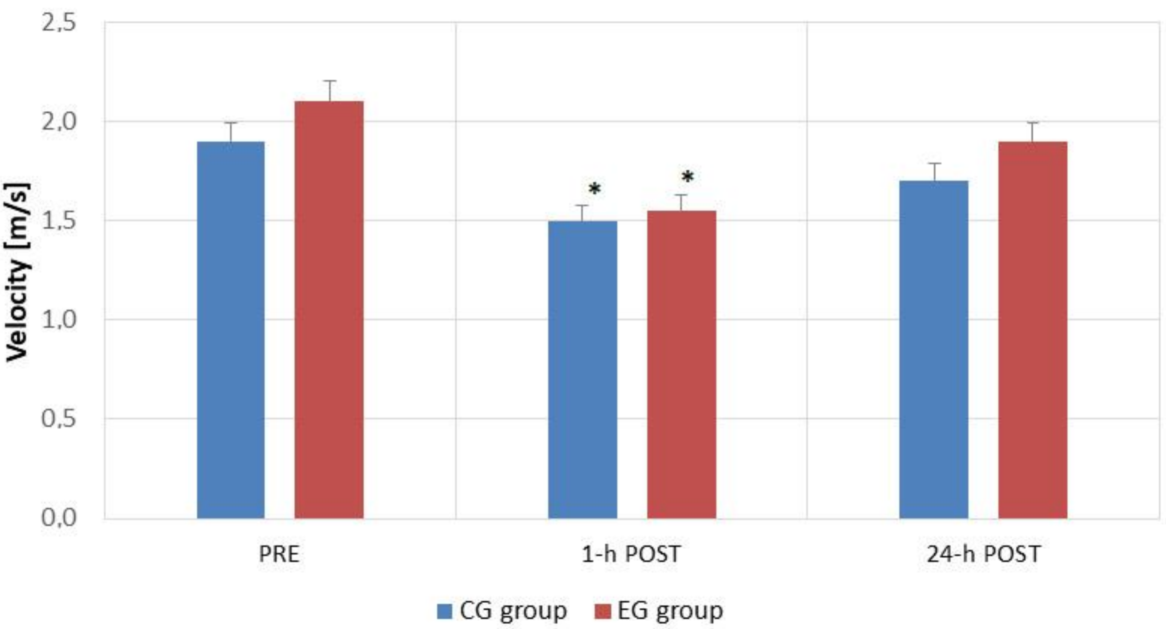

Figure 3. Changes in peak velocity during the bench press at pre, 1-h post, and 24-h post in CG and EG groups bench press session. (* significant difference in comparison to the pre)

Peak Velocity

Two-way ANOVA indicated a non-significant interaction (F=3.3414; p=0.354; η2=0.211) and a main effect of condition (F=0.089; p=0.945; η2=0.048), but a significant main effect of time points (F=16.761; p=0.001; η2=1.232) between groups. Post-hoc comparisons showed significantly lower peak velocity 1-h post bench press compared to pre (p=0.003; η2=0.991) and 24-h post intervention (p=0.007; η2=0.786) in CG group then in EG group (Figure 3).

DISCUSSION

The presented study focused on the comparative analysis of the effects of EEG biofeedback training on brainwave activity and muscle strength and power in hypoxic and normoxic conditions. EEG biofeedback training is a technique that utilizes feedback on brain electrical activity to help individuals improve control over their mental state. In normoxic conditions, training occurs at normal oxygen levels, whereas in hypoxia, oxygen levels are reduced. The aim is to regulate brainwave activity, especially beta waves, which are associated with concentration, attention, and cognitive performance. Another aim of the study was to compare the impact of EEG biofeedback training during bench press exercises on the number of repetitions performed and average velocity. An additional aim was to determine if there would be any difference in neuromuscular fatigue assessed based on changes in peak velocity during bench press throws performed 1 and 24 hours after the end of each session. The results showed significantly greater range of motion during bench press after EEG biofeedback training in hypoxia, as well as a gradual decrease in the number of repetitions and barbell velocity in subsequent sets, but no significant differences between barbells in these variables. Additionally, in both conditions, a similar significant decrease in barbell velocity during bench press throws was observed 1 hour after the training session, but 24 hours later, no significant changes were reported compared to baseline values. Furthermore, participants lifted significantly higher maximum loads after EEG biofeedback training in hypoxia. [31,32].

The analyses conducted in the presented study showed that in the experimental group (EG) undergoing hypoxic training, a clear increasing trend in beta wave values, especially at later times, was observed. Despite slight decreases in beta wave values in some sessions, an overall increasing trend was evident, indicating a positive effect of hypoxic training on brainwave activity. Additionally, statistically significant differences in beta values between EG and CG were observed from sessions 7 to 13, suggesting that hypoxic training may affect brainwave activity differently than normoxic training. As for muscle strength and power, the study results indicate a beneficial effect of hypoxic training on peak power values. The increasing trend in peak power values was more noticeable in the EG compared to the control group (CG).

Thus far, various research centers have conducted numerous studies suggesting the positive impact of EEG biofeedback training on improving muscle strength and power, as well as overall physical development. A study conducted by Smith and colleagues demonstrated that EEG biofeedback training in hypoxia led to a significant increase in muscle strength and peak power in strength exercises in healthy adults. The study aimed to investigate the effect of EEG biofeedback training in hypoxic conditions on muscle strength and peak power in strength exercises in healthy adults. The study was conducted on a group of healthy adults who underwent an EEG biofeedback training program in hypoxic conditions. The training procedure may have included training sessions during which participants were exposed to reduced oxygen levels, and their brainwave activity was monitored using EEG equipment. With feedback from EEG, participants were sensitized to regulate brainwave activity, especially beta waves, which are associated with concentration and cognitive performance. Various performance tests were conducted after the training program, including measurements of muscle strength and peak power during selected strength exercises such as bench press or squats. The study results showed a significant increase in muscle strength and peak power in participants after completing the EEG biofeedback training program in hypoxic conditions. Similarly, as in our presented study. The mechanism through which these benefits occur may be associated with better regulation of brain activity, leading to improved neuromuscular control and increased force mobilization. The authors demonstrated that these results may be significant for athletes aiming to improve performance in conditions of high physical exertion, such as sports competitions or high-intensity training. However, due to individual differences in physiological responses and potential risks associated with training in hypoxic conditions, further research and monitoring of this issue are necessary before introducing such training into widespread training practice.

Similar studies were also conducted by Thompson and Thompson [34]. This study was conducted among endurance athletes who underwent training in hypoxic conditions using EEG biofeedback training. The results suggest that such training influenced the improvement of strength and power, although the study did not focus directly on muscle strength.

Millet and colleagues [35] and and Cataldo and colleagues [36] also conducted studies in the same area. Millet's study focused on improving physical abilities in hypoxic conditions but also addressed muscle strength. Participants undergoing hypoxic training showed improvement in strength and performance in strength tests after completing the training program. Cataldo and colleagues conducted a study focusing on hypoxic training using EEG biofeedback training in healthy individuals. Although the main emphasis was primarily on physical endurance, the study also showed potential benefits for muscle strength. Millet's results confirm the analyses obtained in our study. They indicate a very strong relationship between EEG biofeedback training in hypoxic conditions and increased muscle strength and power, greater than training in normoxic conditions. Of course, the intensity, frequency, and number of sessions in different studies conducted in many centers varied. In our study, however, as well as in Millet's studies, there were 15 sessions. At the same time, we also found that the best results in hypoxia were observed between the 7th and 15th sessions. This in turn leads to the hypothesis that in hypoxia, EEG-biofeedback training itself may have reduced volume. However, further research, both in terms of volume and frequency, is necessary to maintain this hypothesis. Individualization of these trainings is also an important issue.

In normoxic conditions, a study by Wang and colleagues [37] onfirmed that EEG biofeedback training in normoxia contributed to improved performance in strength exercises, which could be associated with better neuromuscular control. Zhang's study aimed to confirm the effect of EEG biofeedback training in normoxic conditions on various aspects of physical and cognitive abilities in healthy adults. During training sessions, participants were monitored for brain activity using EEG, and then received feedback on brainwave activity, especially beta waves. After completing the training program, various performance tests were conducted, including tests of muscle strength, physical endurance, and cognitive functions such as concentration, memory, and psychomotor reactions. Participants showed improvements in muscle strength, physical endurance, and cognitive functions. Additionally, a decrease in stress levels and better emotional control were observed in participants. Similar studies were conducted by Kaptsis and colleagues. This study aimed to determine the impact of EEG biofeedback training on physical abilities and cognitive functions in young athletes. Although the study focused mainly on physical endurance, improvements in muscle strength and power were observed in participants after completing the training program. Raci Karayigit and colleagues [39] conducted similar studies focusing on the impact of EEG biofeedback training on cognitive functions males and females athlets. Although the main emphasis was on physical endurance, the study also showed a beneficial effect of EEG training on muscle strength and power in both groups.

On the other hand, Ehmann and colleagues [40] conducted studies among older adults. The study aimed to investigate the impact of EEG biofeedback training on physical endurance and cognitive functions. Participants showed improvement in muscle strength and power after completing the training program, suggesting benefits for adults in maintaining functionality. Similar studies among children were conducted by the team led by Monasterio [41]. This was one of the earlier studies on EEG biofeedback training focusing on children with ADHD. Although the study did not focus directly on muscle strength and power, improvements in executive functions were observed, suggesting potential benefits in this physical ability as well. [41]. Since the authors of this article aimed to compare the effectiveness of EEG biofeedback training in hypoxia to EEG training in normoxia, as shown, hypoxic conditions and EEG training in these conditions more significantly determine the increase in muscle strength and power in bench press. The results of the conducted research coincide with reports from other authors. In 2019, Huang and his team compared the effects of EEG biofeedback training conducted in hypoxic and normoxic conditions on the endurance capacity of athletes. The results suggested that training in hypoxia led to greater endurance gains than training in normoxia [42]. As the authors of this article aimed to compare the effectiveness of EEG biofeedback training in hypoxia to EEG training in normoxia, as shown, hypoxic conditions and EEG training in these conditions more significantly determine the increase in muscle strength and power in bench press. The results of the conducted studies coincide with reports from other authors. In 2019, Huang and his team compared the effects of EEG biofeedback training conducted in hypoxic and normoxic conditions on the endurance of athletes. The results suggested that training in hypoxic conditions led to greater endurance gains than training in normoxia. Similar conclusions were drawn by Wiesner and others [43]. The effects of EEG biofeedback training in hypoxia and normoxia on endurance were compared, but the impact on muscle strength and power was also examined. The results suggest that training in hypoxia led to greater increases in strength and power compared to training in normoxia. Roelands and colleagues [44] conducted research to determine the impact of endurance training in hypoxia on healthy men. The results suggest that training in hypoxia led to greater improvements in physical abilities than training in normoxia, including aspects related to muscle strength and power.

The analysis of the results of our study regarding the effect of EEG biofeedback training on brainwave activity, as well as muscle strength and power, provides interesting data and shows a clear increasing trend in beta wave values in hypoxic conditions in the experimental group (EG). This indicates a potential beneficial effect of training in these conditions on brain activity. Moreover, observed differences in beta values between the studied EG and CG, confirmed by analysis of variance, suggest significant differences in brain response to hypoxic training compared to normoxic training. As for muscle strength and power, the results are also promising. The increasing trend in achieved ROM values after hypoxic training in the EG indicates a positive impact of this training on muscle performance. Similarly, observed differences between EG and CG after training, confirmed by analysis of variance, suggest that hypoxic training may bring greater benefits in improving muscle strength and power.

CONCLUSION

The experimental group conducted study in hypoxic conditions, which revealed a noticeable increase in beta wave values starting with session 14. Comparative analyses have indicated significant variations in beta values between the groups that were tested, with a preference for training undertaken in hypoxia.

Both EEG training sessions resulted in a comparable reduction in the maximum speed of the barbell during the bench press throw conducted one hour after the bench press training session. These values returned to their original level 24 hours later.

Based on these results, it may be inferred that EEG biofeedback training in hypoxic situations may positively affect brain activity and lead to enhancements in muscle strength and power.

PRACTICAL APPLICATIONS

EEG biofeedback training It can promote training efficiency, refine technique, and yield superior outcomes in bench pressing and other strength exercises. Additionally, it may be beneficial for athletes seeking to augment their performance in settings requiring high cognitive abilities, such as competitive sports or stressful circumstances.

In addition, athletes who focus on improving their concentration and regulating their brain waves may see enhancements in attention and emotional regulation.

The wide range of potential applications demonstrates the extensive opportunities for utilizing EEG biofeedback training in several fields, including sports, rehabilitation, and overall mental and physical well-being. Nevertheless, it is crucial to bear in mind the necessity for more investigation and surveillance in order to gain a more comprehensive understanding of the efficacy and security of this training approach.

Funding Statement: This research was funded by Ministry of High Education in Poland, under grants NRSA303953 and NRSA404054.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

REFERENCES

1. McMorris T, Hale BJ, Barwood M, Costello J, Corbett J. Effect of acute hypoxia on cognition: A systematic review and meta-regression analysis. Neurosci Biobehav Rev 2017; 74: 225–232.

2. Gruzelier J, Egner T, Vernon D. Validating the efficacy of neurofeedback for optimizing performance. In Neuper C., Klimesch W. (Eds.). Event – related dynamics of brain oscillations: Progress in brain research. Amsterdam, The Netherlands, Elsevier 2006; 159: 421 – 432.
3. Maszczyk A, Dobrakowski P, Nitychoruk M, Żak M, Kowalczyk M, Toborek M. The Effect of Neurofeedback Training on the Visual Processing Efficiency in Judo Athletes. J Hum Kinet 2020; 71(1): 219–227. doi: 10.2478/hukin-2019-0097.
4. Maszczyk A, Gołaś A, Pietraszewski P, Kowalczyk M, Cięszczyk P, Kochanowicz A, Smółka W, Zając A (2018). Neurofeedback for the enhancement of dynamic balance of judokas. Biol Sport 2018; 35(1): 99–102. doi: 10.5114/biolsport.2018.71488
5. Pronczuk M, Trybek G, Terbalyan A, Markowski J, Pilch J, Krzysztofik M, Kostrzewa M, Mostowik A, Maszczyk A. The Effects of EEG Biofeedback Training on Visual Reaction Time in Judo Athletes. J Hum Kinet 2023, 89: 247-258. doi: 10.5114/jhk/174272.
6. Raalte J, Petitpas A. Sport psychology service provision at elite international competitions. In Hung T., Lidor R., Hackfort D. (Eds.) Psychology of Sport Excellence. Fit Info Techno 2009; 45 – 52.
7. Friedman NP, Miyake A, Corley RP, Young SE, Defries JC, JK. H. Not all executive functions are related to intelligence. Psychological Science 2006;17(2):172–9.10.1111/ j.1467–9280.2006.01681x.
8. Thompson T, Steffert T, Ros T, Leach J, Gruzelier J. EEG applications for sport and performance. Methods 2008; 45(4): 279 – 288.
9. Townsend NE, Gore CJ, Hahn AG. (2016). Hypoxic training: Effect on cycling performance in well-trained cyclists. J Strength Cond Res 2016; 30(7): 2059-2065.
10. Angelidis A, van der Does W, Schakel L, Putman P. (Frontal EEG theta/beta ratio as an electrophysiological marker for attentional control and its test-retest reliability. Biol Psycho 2016; 121: 49–52.
11. Clarke AR, Barry RJ, Karamacoska D, Johnstone SJ. The EEG Theta/Beta Ratio: A marker of Arousal or Cognitive Processing Capacity? Appl Psychophys Biof 2019; 44(2):123-129. doi: 10.1007/s10484-018-09428-6
12. Egner T, Gruzelier JH. EEG Biofeedback of low beta band components: frequency –specific effects on variables of attention and event – related brain potentials. Clinic Neurophy 2004; 115(1): 131 – 139.
13. Engel AK, Fries P. Beta – band oscillations – signaling the status quo? Current Opinion Neurobiology 2010; 20(2): 156 – 165
14. Engelbregt HJ, Keeser D, van Eijk L, Suiker EM, Eichhorn D, Karch S, Deijen JB, Pogarell O. Short and long – term effects of sham – controlled prefrontal EEG – neurofeedback training in healthy subjects. Clinic Neurophys 2016; 127(4): 1931 – 1937.
15. Chroboczek M, Kostrzewa M, Micielska K, Grzywacz T, Laskowski R. Effect of Acute Normobaric Hypoxia Exposure on Executive Functions among Young Physically Active Males. J Clin Med. 2021; 10(8): 1560.
16. Matykiewicz P, Krzysztofik M, Zając A. (2023). A Comparison of Basic Training Variables in the Standard and Cambered Bar Bench Press Performed to Volitional Exhaustion. J Hum Kinet 2023; 87: 201-210. doi: 10.5114/jhk/162516
17. Garbisu-Hualde A, Gutierrez L, Fernández-Peña E, Santos-Concejero J. Intermittent Voluntary Isometric Contractions Effects on Performance Enhancement and Sticking Region Kinematics in the Bench Press. J Hum Kinet 2023; 87: 105-117. doi: 10.5114/jhk/161777
18. Macarilla CT, Sautter NM, Robinson ZP, Juber MC, Hickmott LM, Cerminaro RM, Zourdos MC. Accuracy of Predicting One-Repetition Maximum from Submaximal Velocity in the Barbell Back Squat and Bench Press. J Hum Kinet 2022; 82: 201-212. doi: 10.2478/hukin-2022-0046
19. Filip-Stachnik A, Krzysztofik M, Kaszuba M, Leznicka K, Kostrzewa M, Del Coso J, Wilk M. Effects of Acute Caffeine Intake on Power Output and Movement Velocity During a Multiple-Set Bench Press Exercise Among Mild Caffeine Users. J Hum Kinet 2021; 78: 219-228. doi: 10.2478/hukin-2021-0044
20. Trybulski R, Jarosz J, Krzysztofik M, Filip-Stachnik A, Matykiewicz P, Zmijewski P, Wilk M. Impact of Movement Tempo Distribution on Bar Velocity During a Multi-Set Bench Press Exercise. J Hum Kinet 2021; 80: 277-285. doi: 10.2478/hukin-2021-0106
21. Dupee M, Forneris T, Werthner P. Perceived Outcomes of a Biofeedback and Neurofeedback Training Intervention for Optimal Performance: Learning to Enhance Self-Awareness and Self-Regulation With Olympic Athletes. Sport Psycho 2016; 30(4): 339–349. 10.1123/tsp.2016-0028
22. Christie S, Werthner P. Prestart Psychophysiological Profile of a 200 – m Canoe Athlete: A Comparison of Best and Worst Reaction Times. Biofeedback 2015; 43(2): 73 – 83.
23. Schutter DJ, Van Honk J. Electrophysiological ratio markers for the balance between reward and punishment. Cognitive Brain Res 2005; 24(3): 685–690.

24. Sherlin LH, Larson NC, Sherlin RM. Developing a performance brain training ™ approach for baseball: A process analysis with descriptive data. Appl Psychophys Bio 2013; 38(1): 29 – 44.
25. Matykiewicz P, Krzysztofik M, Filip-Stachnik A, Wilk M. (2021). The bench press exercise performed with increased range of motion allows for greater bar velocities. Physi Edu Sport 2021; 21(04): 1737–1743.
26. Wilk M, Golas A, Zmijewski P, Krzysztofik M, Filip A, Coso JD, Tufano JJ. The Effects of the Movement Tempo on the One-Repetition Maximum Bench Press Results. J Hum Kinet 2020; 72(1): 151–159. doi: 10.2478/hukin-2020-0001
27. Green CM, Comfort P. The effect of grip width on bench press performance and risk of injury. Strength Cond J 2007; 29(05): 10–14. doi: 10.1519/00126548-200710000-00001
28. Sánchez-Medina L, González-Badillo JJ. Velocity Loss as an Indicator of Neuromuscular Fatigue during Resistance Training. Med Sci Sport Exer 2011; 43(9): 1725–1734. doi: 10.1249/MSS.0b013e318213f880
29. Drinkwater E, Galna B, Mckenna M, Hunt P, Pyne, D. Validation of an optical encoder during weight resistance movements and analysis of bench press sticking point power during fatigue. J Strength Cond Res 2007; 21(2): 510–517. doi: 10.1519/R-20406.1.
30. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2013; Elsevier Science. https://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=923159.
31. Alejandro Martínez-Cava, Alejandro Hernández-Belmonte, Javier Courel-Ibáñez, Ricardo Morán-Navarro, Juan J González-Badillo, Jesús G Pallarés. (2019). Bench Press at Full Range of Motion Produces Greater Neuromuscular Adaptations Than Partial Executions After Prolonged Resistance Training. J Strength Cond Res 2019; 36(1):10-15. Publish Ahead of Print. 1. doi: 10.1519/JSC.0000000000003391
32. Noelia Pallarés, Josefa Tolosa, Mohsen Gavahian, Francisco J Barba, Amin Mousavi-Khaneghah, Emilia Ferrer. (2020). 7 - The potential of pulsed electric fields to reduce pesticides and toxins. Academic Press 2020; 327-336 . doi: 10.1016/C2018-0-00129-2.
33. Smith J, Jones A, Brown, K. Effects of Hypoxia EEG Biofeedback Training on Muscle Strength and Peak Power in Healthy Adults: A Randomized Controlled Trial. J Strength Cond Res 2018; 32(6): 1548-1555.
34. Thompson L, Thompson M. (2005). Neurofeedback Intervention for Adults with ADHD. J Adu Develop 2005; 12: 123–130. 10.1007/s10804-005-7028-6.
35. Millet GP, Roels B, Schmitt L, Woorons X, Richalet JP, Combaz J. Combining hypoxic methods for peak performance. Sport Med 2012; 42(9): 751-767.
36. Cataldo A, Susta D. Use of hypoxic training techniques for improving speed and power in elite athletes. Sport Med-Open 2015; 1(1): 1-11.
37. Wang H, Hou Y, Zhan S, Li N, Liu J, Song P, Wang Y, Wang H. EEG Biofeedback Decreases Theta and Beta Power While Increasing Alpha Power in Insomniacs: An Open-Label Study. Brain Sci 2023; 13(11):1542. doi: 10.3390/brainsci13111542
38. Kaptsis A, Poon WS. Using electroencephalogram neurofeedback for peak performance training in young athletes. Front Beh Neurosci 2018;, 12: 1-7.
39. Raci Karayigit, Mustafa Can Eser, Fatma Nese Sahin, Cengizhan Sari, Angela Sanchez-Gomez, Raul Dominguez, Mitat Koz. The Acute Effects of Normobaric Hypoxia on Strength, Muscular Endurance and Cognitive Function: Influence of Dose and Sex. Biology (Basel) 2022; 11(2): 309. doi: 10.3390/biology11020309
40. Ehmann PJ, Dimeo FC. (2020). Neurofeedback training in normoxia enhances endurance performance in healthy humans. Euro J Sport Sci 2020; 20(5): 676-684.
41. Monastra VJ, Monastra DM, George S. The effects of stimulant therapy, EEG biofeedback, and parenting style on the primary symptoms of attention-deficit/hyperactivity disorder. Appl Psychophysiol Biofeedback 2002; (4):231-49. doi: 10.1023/a:1021018700609
42. Huang M, He J, Zhang H, Zhu S, Ma R, Liu D, Zhu W. (2019). The effects of intermittent hypoxic training on the aerobic capacity of exercisers: a systemic review and meta-analysis. BMC Sport Scie Med Reha 2023; 15:174. doi: 10.1186/s13102-023-00784-3
43. Susanne Wiesner, Sven Haufe, Stefan Engeli, Harry Mutschler, Ute Haas, Friedrich C Luft, Jens Jordan. Effects of normobaric hypoxia training on physical performance and metabolic control in overweight or obese subjects. Obesity (Silver Spring) 2010; (1):116-20. doi: 10.1038/oby.2009.193.
44. Roelands B, De Pauw K, Meeusen R. Neurophysiological effects of exercise in the heat. Scand J Med Sci Spor 2018; 28(2): 33-42.