SHORT COMMUNICATION

Pol J Aviat Med Bioeng Psychol 2025; 31(1): 24-31
DOI: 10.13174/pjambp.20.02.2026.04

THE IMPACT OF MINDFULNESS MEDITATION ON CHANGES IN RESTING-STATE ALPHA RHYTHM ACTIVITY IN COMPETITIVE ATHLETES: A PRELIMINARY REPORT

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Source of support: This research received no external funding

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Introduction: The aim of this study was to evaluate the effect of short-term mindfulness meditation training on the bioelectrical activity of the brain in elite athletes. Thirty-two athletes competing at the national team or Polish championship level participated in the study, representing swimming (n = 10), judo (n = 15), and water polo (n = 7). All participants completed a 7-day mindfulness meditation training program.

Methods: Brain bioelectrical activity was assessed using quantitative electroencephalography (QEEG) before and after the training cycle. Recordings were obtained from 15 electrodes positioned according to the international 10–20 system. Absolute alpha frequency power (8–12 Hz) and the alpha/beta ratio (alpha: 8–12 Hz; beta: 15–20 Hz) were analyzed. The Wilcoxon signed-rank test was applied to compare pre- and post-intervention measurements across all 15 EEG sites, with additional subgroup analyses according to sport discipline.

Results: Statistical analysis showed significant changes in EEG activity after the 7-day mindfulness training only in selected subgroups of athletes. The most pronounced effects were found in right-handed female judo athletes, who demonstrated a decrease in alpha power at electrodes Cz and C4, along with an increase in the alpha/beta ratio at electrodes P3 and Pz. No statistically significant differences were found in the overall study group; however, the lowest p-values ($p < 0.07$) suggested trends toward changes at electrodes C4, F8, and Cz.

Discussion and Conclusions: The findings suggest that a brief mindfulness intervention may modulate brain bioelectrical activity in a manner dependent on sex and sport discipline. The observed changes may be related to improvements in self-regulation, attentional control, and perceptual-motor preparation. These findings are preliminary. Further research involving larger samples and task-based conditions is required to more precisely determine the significance of these effects for athletes' functioning and performance.

Keywords: EEG, QEEG, mindfulness, alpha frequency, mental training, self-regulation, sport

Cite this article: Budzis J, Rola R: The Impact of Mindfulness Meditation on Changes in Resting-State Alpha Rhythm Activity in Competitive Athletes: A Preliminary Report. Pol J Aviat Med Bioeng Psychol 2025; 31(1): 24-31. DOI: 10.13174/pjambp.20.02.2026.04

INTRODUCTION

Mindfulness techniques have gained prominence as effective tools for supporting mental health, including improvements in concentration, cognitive functioning, and emotion regulation. "The demonstrated impact of mindfulness meditation practice on structural and functional brain changes has led to extensive scientific investigation, including in the field of competitive sports. Interest in mindfulness among athletes primarily centers on its role in emotion regulation, concentration, and adaptation to competitive stress." The effectiveness of short-term mindfulness training in enhancing executive functions and self-regulation has been confirmed in studies conducted outside the sports context [21], particularly in relation to increased activation of brain structures associated with self-control, attention, and inhibition of impulsive responses.

Mindfulness is defined as a receptive awareness of present-moment experience. It is built upon two core constructs - awareness and attention - that facilitate being fully "Here and Now" through deliberate engagement with ongoing experience and sensory information. Mindfulness is conceptualized as a state of consciousness in which individuals intentionally experience situations moment by moment in a non-judgmental manner, without engaging discriminative, categorizing, or habitual beliefs and thoughts [4]. Accordingly, mindfulness training involves the deliberate direction of attention toward ongoing experience, characterized by acceptance and non-judgment [4]. A substantial body of research indicates that regular meditation practice may induce changes in brain functioning, including increased alpha wave power and enhanced integration of bioelectrical activity in frontal and central regions [7,22].

In the context of sport, mindfulness training shows positive biological and psychological effects on athletes' functioning, and thus also their sport-specific performance capacity. These changes include alterations in hormonal system functioning as well as structural and functional brain changes within the prefrontal cortex, hippocampus, insula, and amygdala, leading to improved concentration, arousal regulation, and coping with pressure [2,8]. Moreover, mindfulness training positively affects the risk of burnout and perceived anxiety, directly influencing performance outcomes. Enhancement of concentration and attention through mindfulness training also assists athletes in minimizing task-irrelevant thoughts, thereby reducing the risk of choking under pressure, injury occurrence, and subsequent withdrawal from the training process [16].

EEG examinations indicate that individuals practicing meditation exhibit characteristic cortical activity patterns, including increased resting-state alpha power and beta-band changes during focused attention [5]. These changes are associated with improvements in performance-related parameters such as movement precision, reaction time, and emotional regulation [20]. Research on the effects of meditation techniques on central nervous system bioelectrical activity distinguishes between changes occurring during meditation practice (state effects) and those persisting at rest as a result of long-term practice (trait effects) [12].

Electroencephalography (EEG) is a non-invasive method used to record brain bioelectrical activity via electrodes placed on the scalp. Quantitative EEG (QEEG) extends standard EEG examinations by converting raw recordings into numerical data, enabling objective assessment of power distribution across specific frequency bands in defined cortical locations.

The alpha/beta ratio is frequently employed in QEEG analysis and reflects the relationship between signal power in the alpha (8-12 Hz) and beta (15-20 Hz) frequency bands. The signal power is automatically calculated by the Elmiko EEG system software according to the formula [9]:

$$P = c \cdot \Sigma_{m=m1}^{(m2)} |X(m)|^2$$

The alpha/beta ratio is used to evaluate the regulation of cortical arousal [23]. In individuals with ADHD, this ratio is often elevated, with the brain operating in a state dominated by alpha power and demonstrating difficulty with activation [11,19]. In individuals with anxiety disorders, it may be reduced, reflecting beta-band predominance and excessive vigilance [17]. In neurofeedback training, this ratio is applied to achieve arousal balance by increasing alpha activity for relaxation or decreasing beta activity to reduce tension [6,15].

Although the theta/beta ratio predominates in ADHD-related clinical literature, the alpha/beta ratio is sometimes employed as a broader marker of cortical arousal balance and attentional control. EEG findings in ADHD indicate an excess of slower rhythms accompanied by relatively reduced faster (beta) activity, interpreted as a profile of increased "vigilance without direction" and difficulty engaging task-related networks [3,10,11]. Within this framework, a higher alpha/

beta ratio may reflect a more relaxed resting state with reduced beta vigilance, whereas a lower alpha/beta ratio may indicate heightened vigilance and tension [17].

Despite the increasing number of reports on the neurophysiological effects of mindfulness, studies employing quantitative EEG (QEEG) in elite, championship-level athletes remain limited. The present study aimed to evaluate the impact of short-term mindfulness meditation training on the bioelectrical activity of the central nervous system in athletes representing three Olympic disciplines: swimming, judo, and water polo. Particular emphasis was placed on changes in alpha-band EEG power and the alpha/beta ratio, analyzed within a pre-post training framework, with additional consideration of variables such as sport discipline.

METHODS

Participants

The study included 32 athletes representing three sports disciplines: swimming (n = 10), judo (n = 15), and water polo (n = 7). Participants were right-handed (n = 30), left-handed (n = 1), or reported ambidexterity (n = 1). The sample comprised 16 women and 19 men. Inclusion criteria were: age between 16 and 32 years, membership in a national team or championship-level competition, absence of active neurological disorders, and consent to participate in the 7-day experimental protocol. All participants engaged in regular competitive-level sports training. During the experimental period, judo and swimming athletes trained on average 10 times per week, with each session lasting approximately 120 minutes. Water polo athletes trained on average 5 times per week, with each session also lasting approximately 120 minutes. The study was conducted following approval from the Bioethics Committee of Jan Kochanowski University of Kielce (No. 32/2022).

Apparatus and Procedure

EEG recordings were obtained using a 32-channel, medically certified Elmiko EEG DigiTrack system [9]. Recordings were collected from 15 electrode sites: F3, F4, F7, F8, Fz, C3, Cz, C4, P3, Pz, P4, T3, T4, T5, and T6. Electrodes were placed on the scalp using an EEG cap with conductive paste, in accordance with the international 10-20 system. A physical reference electrode was positioned on the auricle. Recording parameters included a high-pass filter: 0.3s, a low-pass filter: 70 Hz, and a 50 Hz notch filter.

EEG was recorded under resting-state conditions (eyes closed) in a supine position for 5-10 minutes. Artifacts (e.g., eye movements, muscle tension) were identified and removed both manually and automatically during quantitative analysis. Each participant underwent EEG assessment twice: one day before and one day after completion of the 7-day mindfulness training cycle. The experimental protocol consisted of daily mindfulness sessions lasting 10 minutes, conducted twice per day in a room setting. The experimenter guided the meditation sessions by instructing participants to focus on their breath and bodily sensations. Participants performed the meditation in a comfortable supine or seated position with eyes closed. The room environment was quiet with dim lighting. In addition to the instructor's verbal guidance, calm music and nature sounds were played in the background.

EEG data were analyzed using quantitative EEG (QEEG), focusing on absolute alpha power (8-12 Hz) and the alpha/beta ratio, calculated as the ratio of alpha-band power (8-12 Hz) to beta-band power (15-20 Hz).

Statistical Analysis

To evaluate the effect of the 7-day mindfulness training on EEG activity, the Wilcoxon signed-rank test for paired samples was applied, comparing signal power and alpha/beta ratio measurements obtained before and after the intervention across all 15 electrodes. A significance level of $p < 0.05$ was adopted. All analyses were performed in the Python environment (pandas, scipy, seaborn libraries).

RESULTS

None of the analyzed electrodes reached statistical significance ($p < 0.05$); however, several sites yielded p-values approaching significance, suggesting the presence of subtle effects. The lowest p-values were observed for electrode C4 (alpha/beta ratio): $p = 0.068$; mean change −0.76, F8 (alpha power): $p = 0.098$; mean change +1.05, Cz (alpha/beta ratio): $p = 0.119$; mean change −0.59, C4 (alpha power): $p = 0.124$; mean change −6.87, and Cz (alpha power): $p = 0.142$; mean change −8.41, (Fig. 2). These findings suggest small but directionally consistent changes within central and frontotemporal regions.

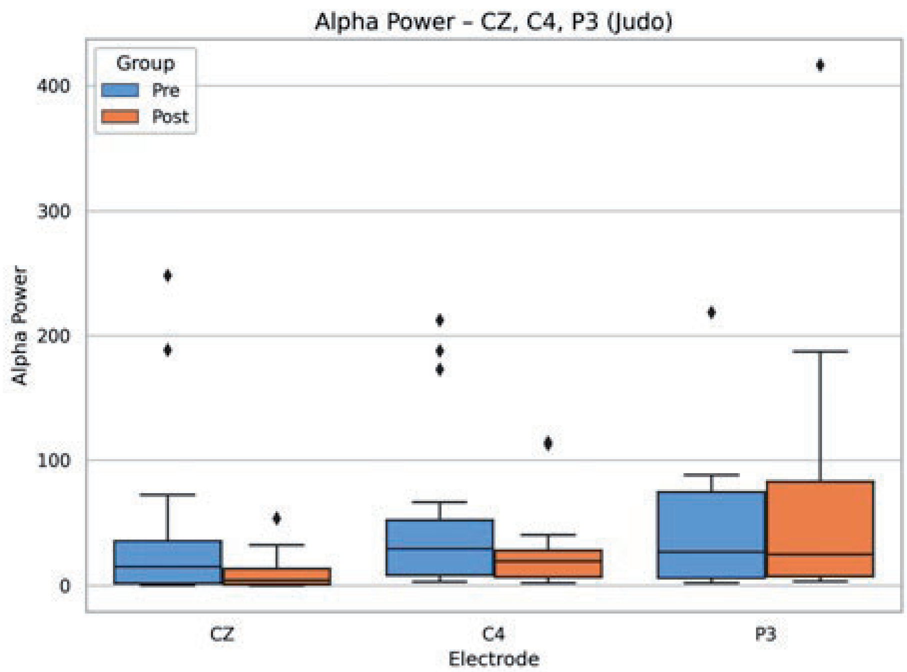

Fig. 1. Pre- and post-training alpha power results in judo for Cz, C4, and P3 electrodes.

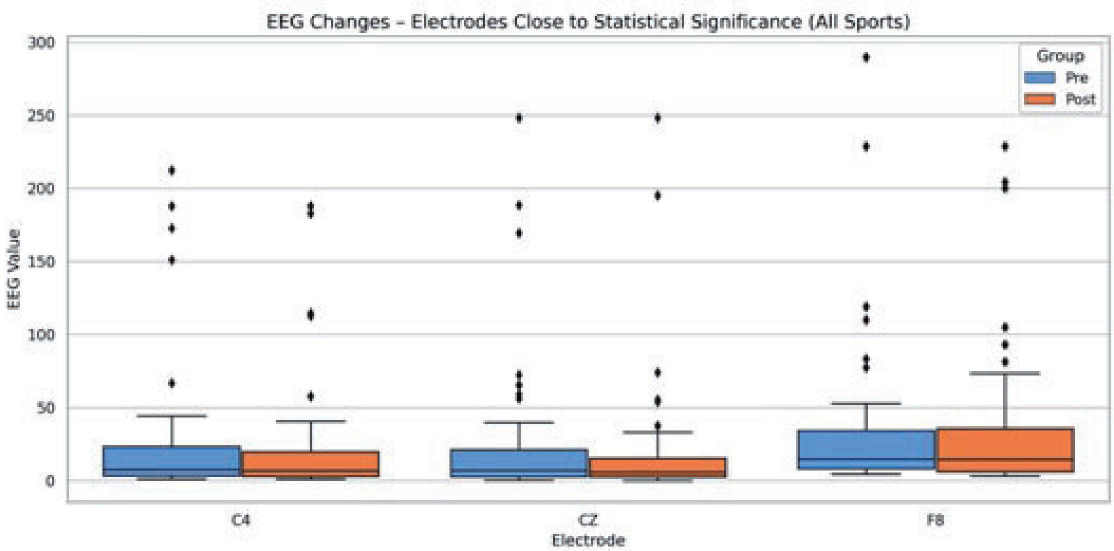

Fig. 2. Pre- and post-training alpha power results for C4, Cz, and F8 electrodes (all sports).

Separate analyses conducted for each sport discipline using the Wilcoxon signed-rank test (pre–post comparison) revealed statistically significant differences primarily in the judo group and at one site among swimmers. In the judo group (N = 15), women (n = 15), a significant decrease in alpha-band EEG power following the mindfulness intervention was observed at Cz ($p = 0.007$; mean change –32.9 μV^2) and C4 ($p = 0.048$; mean change –26.5 μV^2). Within the same group, a significant increase in alpha power was found at P3 ($p = 0.026$; mean change +27.3 μV^2) (Fig. 1). Additionally, a significant increase in the alpha/beta ratio was observed at Pz ($p = 0.022$; mean change +2.99) (Fig. 4).

In the swimmers group (N = 10), men (n = 9), women (n = 1), the only statistically significant change was a decrease in alpha power at T6 ($p = 0.049$; mean change –20.5 μV^2) (Fig. 3). In the water polo group (N = 7), men (n = 7), no statistically significant changes were detected in any of the analyzed indicators or electrode sites.

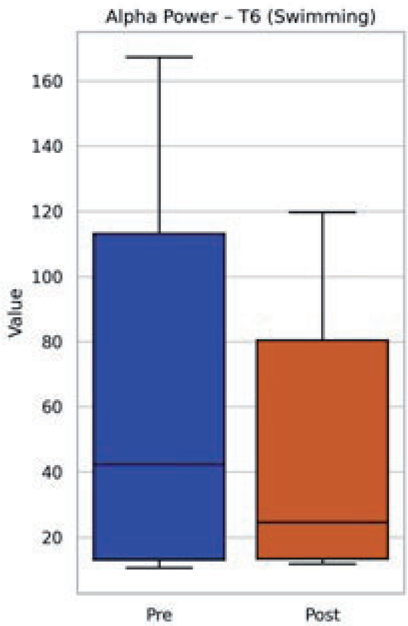

Fig. 3. Pre- and post-training alpha power results in swimming for T6 electrode.

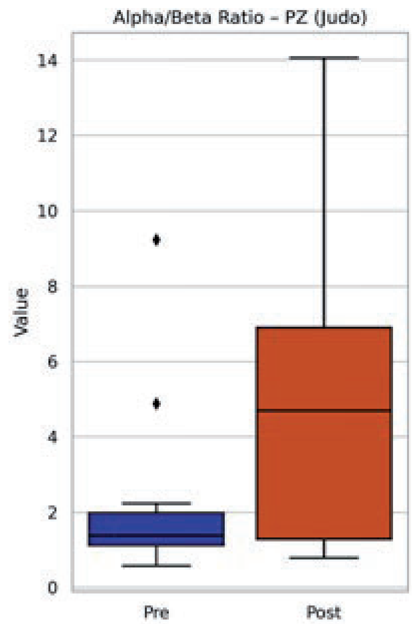

Fig. 4. Pre- and post-training alpha/beta ratio results in judo for Pz electrode.

In summary, the most pronounced effects of mindfulness training were observed in female judo athletes, encompassing both decreases and increases in the examined EEG parameters, predominantly within central and parietal regions. Among swimmers, the effect was limited to a single derivation over the right temporal lobe (T6), whereas no significant changes were identified in the water polo group. These findings indicate differential sensitivity across sports disciplines to short-term mindfulness training in relation to the analyzed EEG parameters and the intensity of physical activity, understood as the number of training hours per week.

DISCUSSION

The present findings indicate that a brief, 7-day mindfulness training program may lead to measurable changes in brain bioelectrical activity, particularly within selected subgroups of athletes representing different sports disciplines at the championship level (national and/or international). It is possible that the short duration of the intervention was sufficient to induce EEG changes in some participants. Although the intervention lasted only seven days, previous research suggests [20] that relatively short mental training programs (including elements of body relaxation, mental imagery, and mindfulness practice) may induce structural changes in the white matter of the anterior cingulate cortex, a region associated with attentional control, emotion regulation, and self-regulation.

The decrease in alpha power at Cz and C4 may reflect increased sensorimotor readiness and enhanced cortical involvement in somatosensory processing, in line with previous findings [7]. At the same time, reduced alpha activity within the somatosensory region may be associated with improved attentional focus and a reduction in mind wandering, a state commonly observed during resting conditions with eyes closed or open [18]. Conversely, the increase in alpha power at P3 and the increase in the alpha/beta ratio (reflecting reduced beta activity) at Pz may indicate enhanced cognitive regulation, improved attentional processes, and reduced arousal linked to decreased beta activity (15-20 Hz) in this region. This interpretation is consistent with existing literature [5,22]. Other authors have also suggested that even short-term mindfulness training may induce functional brain changes manifested as increased alpha power, thereby supporting improved emotion regulation [20]. The observed spatial distribution of alpha activity changes - with waves increasing in the direction from the frontal lobe toward the occipital lobe - is consistent with the literature on the subject.

Clinical literature emphasizes substantial interindividual variability in EEG phenotypes, particularly within alpha and beta rhythms [1,3]. This variability reflects differences in baseline cortical arousal and in the relative proportion of slow and fast rhythms, which in turn may influence individual responsiveness to interventions aimed at regulating psychophysiological tension. Moreover, EEG rhythms exhibit task-dependent modulation, with their amplitude and topography varying according to cognitive or emotional context, such as concentration, relaxation, or anticipation of a stimulus [10,11]. In the present study, the increase in the alpha/beta ratio within parietal regions (Pz) may be interpreted as an adaptive reduction in central arousal and enhanced self-regulatory efficiency, whereas the decrease in alpha power in central regions (Cz, C4) may reflect increased sensorimotor readiness. This pattern - simultaneous enhancement of relaxation-related inhibition and central activation - confirms that short-term mindfulness training facilitates flexible regulation of arousal, a characteristic feature of athletes with high levels of somatic control.

The present findings may be compared with those reported by Mikicin and colleagues [13,14], who implemented a complex EEG neurofeedback protocol combined with autogenic and audiovisual relaxation in semi-professional athletes. Those authors observed increased resting-state alpha power (eyes closed), interpreting this effect as indicative of improved attentional and arousal regulation. In contrast, in the present study, modulation of alpha activity emerged following a substantially shorter, seven-day intervention based exclusively on mindfulness training (including body-scan), without neurofeedback or sensory stimulation components. The observed pattern - selective, location- and discipline-dependent changes in alpha power and the alpha/beta ratio - suggests that short-term, purely cognitive-somatic mindfulness practice may induce neurophysiological changes in a direction similar to that observed in longer, more complex training programs.

Differences between studies may be attributable to the sporting level of participants. The athletes included in the present study competed at national team and championship levels, and their nervous systems may be characterized by greater adaptation to stress and superior somatic control, potentially resulting in a faster and stronger neuronal response even to short-term intervention. It is also plausible that the specific demands of particular disciplines - especially judo, which requires continuous regulation of muscle tension, proprioceptive orientation, and rapid reactions - promote greater neuroplasticity and enhanced capacity to modulate sensorimotor rhythms in response to mindfulness training. This may suggest that mindfulness meditation training is particularly effective in supporting cognitive-motor processes in combat sports. The absence of significant changes in the remaining groups may be related to lower intensity of proprioceptive stimulation, reduced internal attentional focus, or insufficient intervention duration. A longer training protocol might reveal stronger effects across a broader range of cortical regions.

These findings open an interesting direction for future research, particularly studies integrating neurofeedback training with mindfulness and body-scan relaxation techniques. Such integrated protocols could simultaneously strengthen neuronal mechanisms of self-regulation (through EEG feedback) while enhancing body awareness and reducing somatic tension. In the future, research of this type may contribute to the development of comprehensive, neurophysiologically informed mental training programs tailored to specific sport disciplines and individual athlete profiles.

The main limitations of the study include the sample size and the absence of a control group. Future research should incorporate larger samples, extended training protocols, and assessment of cortical activity during cognitive tasks or visualizations in order to better elucidate the mechanisms underlying mental training in athletes.

CONCLUSIONS

The present study indicates that a 7-day mindfulness training program does not produce clear, statistically significant changes in EEG activity across the entire sample of competitive athletes. However, subgroup analyses revealed discipline-dependent differences in response, particularly among female judo athletes, in whom changes were observed at central and parietal sites, encompassing both alpha power and the alpha/beta ratio, reflecting alterations in beta-band activity (15-20 Hz).

These findings suggest that the effectiveness of short-term mindfulness interventions may be influenced by the specific characteristics of the sport discipline, the level of somatic control, and prior experience with mental training [22]. Changes observed at Cz, C4, P3, and Pz may reflect adaptive mechanisms related to attentional processes, regulation of muscle tension, and sensorimotor integration.

The absence of significant effects in the water polo group and the limited changes observed among swimmers suggest that, in team or endurance sports, brief meditation protocols may not be sufficiently intensive to elicit measurable

EEG changes. This may indicate the need for longer interventions, greater program individualization, or the implementation of alternative forms of mental training.

This study confirms the validity of conducting further analyses on the application of EEG and QEEG in evaluating the effectiveness of psychological interventions in sport. Future research should particularly consider extending the duration of the intervention, examining long-term effects of mindfulness training, incorporating additional psychological variables (e.g., anxiety level, motivation, personality), and exploring individual differences in responsiveness to mindfulness based on athletes' neurophysiological profiles.

AUTHORS' DECLARATION

Study Design: Joanna Budzis, Rafał Rola. **Statistical analysis:** Joanna Budzis, Rafał Rola. Data Collection: Joanna Budzis, Rafał Rola. **Manuscript Preparation:** Joanna Budzis, Rafał Rola. The Authors declare that there is no conflict of interest.

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