



Absolute beta power in exercisers and nonexercisers in preparation for the oddball task

Potência absoluta de beta em praticantes e não praticantes de exercício físico na preparação da tarefa oddball

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Abstract

Background High levels of physical conditioning are associated with improvements in cognitive performance. In this sense, electroencephalographic (EEG) correlates are used to investigate the enhancing role of physical exercise on executive functions. Oscillations in the β frequency range are proposed to be evident during sensorimotor activity.

Objective To investigate the EEG changes influenced by aerobic and resistance exercises performed in an attention task by analyzing the differences in absolute β power in the prefrontal and frontal regions before, during, and after the oddball paradigm in practitioners and nonpractitioners of physical exercise.

Methods There were 15 physical activity practitioners (aged 27 ± 4.71) and 15 nonpractitioners (age 28 ± 1.50) recruited. A two-way analysis of variance (ANOVA) was implemented to observe the main effect and the interaction between groups and moments (rest 1, pre-stimulus, and rest 2).

Results An interaction between group and moment factors was observed for Fp1 ($p < 0.001$); Fp2 ($p = 0.001$); F7 ($p < 0.001$); F8 ($p < 0.001$); F3 ($p < 0.001$); Fz ($p < 0.001$); and F4 ($p < 0.001$). Electrophysiological findings clarified exercisers' specificity and neural efficiency in each prefrontal and frontal subarea.

Conclusion Our findings lend support to the current understanding of the cognitive processes underlying physical exercise and provide new evidence on the relationship between exercise and cortical activity.

Keywords

- Exercise
- Resistance Training
- Executive Function
- Frontal Lobe
- Attention
- Electroencephalography

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Resumo

Palavras-chave

- Exercício Físico
- Treinamento Resistido
- Função Executiva
- Lobo Frontal
- Atenção
- Eletroencefalografia

Antecedentes Níveis elevados de condicionamento físico estão associados a melhorias no desempenho cognitivo. Nesse sentido, correlatos eletroencefalográficos são utilizados na investigação do papel aprimorador do exercício físico sobre as funções executivas. Tem sido proposto que as oscilações na faixa de frequência β são evidenciadas durante a atividade sensório-motora.

Objetivo Investigar as alterações eletroencefalográficas influenciadas por exercícios aeróbio e resistido realizados em uma tarefa atencional analisando as diferenças da potência absoluta de β nas regiões pré-frontal e frontal antes, na preparação e depois do paradigma oddball em praticantes e não praticantes de exercício físico.

Métodos Foram recrutados 15 praticantes de atividade física (idade 27 ± 4.71) e 15 não praticantes (idade 28 ± 1.50). Uma análise de variância (ANOVA) de duas vias foi implementada para observação do efeito principal e a interação entre os grupos e os momentos (repouso 1, pré-estímulo e repouso 2).

Resultados Uma interação entre os fatores grupo e momento para Fp1 ($p < 0,001$); Fp2 ($p = 0,001$); F7 ($p < 0,001$); F8 ($p < 0,001$); F3 ($p < 0,001$); Fz ($p < 0,001$); e F4 ($p < 0,001$) foi observada. Os achados eletrofisiológicos esclareceram a especificidade e a eficiência neural dos praticantes de exercício físico em cada subárea pré-frontal e frontal.

Conclusão Nossos achados promovem o entendimento atual dos processos cognitivos subjacentes ao exercício físico e acrescentam novas evidências sobre a relação exercício e atividade cortical.

INTRODUCTION

Physical exercise has become an important public health tool, primarily due to its impact on conditioning, cardiorespiratory and physiological parameters.¹ However, while the dynamics and regulatory mechanisms of the body's systems and organs through movement are well documented, understanding of cognitive functioning after physical exercise remains incomplete.² Evidence suggests that aerobic and resistance exercises, or combinations of both have facilitative effects on global cognitive development at all ages,^{3–5} enhancing cognitive functions such as attention, which can be observed by behavioral differences in processing speed and reaction time.^{6–8}

For example, cardiorespiratory fitness has been associated with cognitive abilities that are highly dependent on the frontal lobe in individuals over the age of 55;⁹ running improved performance in cognitive tasks associated with neuronal plasticity in the prefrontal cortex;¹⁰ an increase in P300 amplitude was observed after a 15-minute walk outdoors;¹¹ a single session of aerobic and resistance exercises is associated with improved executive function performance, especially attention allocation.^{12,13} Additionally, a recent review analyzed that resistance exercises caused brain changes, especially in the frontal lobe, which were accompanied by executive function improvements;¹⁴ also, exercises contributed to improving the functional plasticity of response inhibition processes in the cerebral cortex;¹⁵ and high-intensity aerobic exercises improved brain activation, reflecting sustained attention during task performance.¹⁶

Electrophysiological correlates indicate that cognitive processes are enhanced over time and that a greater attentive preparatory state is related to higher levels of physical conditioning.⁷ Quantitative electroencephalography (EEGq), through its high temporal resolution, has become a suitable tool for examining the electrocortical dynamics underlying neural processing by physical exercise.^{17,18} It has been proposed that neural oscillations in the β frequency range (13–30 Hz) are evidenced during sensorimotor activity.^{19–21} Other studies have observed that an increase in β after exercise is associated with greater cortical activation and cognitive enhancement.^{22–26} However, although the association between β and motor activity is well-defined, the frequency's functional significance is still debated.

Therefore, there has been an increasing effort to understand how physical exercise affects cognitive functions and cortical activation. However, few studies have reported the effects of the relationship between physical exercise and cognitive functioning on cortical electrophysiological activity during an attention-heavy movement preparation task.

This study aims to investigate the electrophysiological changes influenced by aerobic and resistance exercises in attentional tasks, using the oddball paradigm. Specifically, we aimed to examine changes in absolute β power in the prefrontal and frontal regions among nonexercisers and exercisers. We hypothesize that the group of exercisers will present a greater efficiency in cortical processing and, consequently, a decreased β activity related to the effect of physical conditioning.

METHODS

Sample

We recruited 15 physical activity practitioners (aged 27 ± 4.71) and 15 nonpractitioners (aged 28 ± 1.50), of both sexes, right-handed. The practitioners performed approximately 30 minutes of strength training with both multi and single-joint exercises (50–90% loads of one repetition maximum; 60–90 seconds rest) and 30 minutes of aerobic training (running) at an intensity of 70 to 90% of the maximum heart rate, three times a week for 24 weeks, without interruption. In comparison, nonpractitioners were not physically active in the last 6 months. We utilized the Edinburgh inventory²⁷ to identify and exclude left-handed individuals from the experiment. All subjects signed an informed consent form and were aware of the experimental protocol. The research was approved by the Ethics Committee of the Federal University of Rio de Janeiro (CAAE: 94638124.2.000.3422), according to the Human Research Ethics Criteria included in the Declaration of Helsinki of 1964.

Experimental procedure

The participants sat comfortably in a chair with armrests adjusted according to individuals' height to minimize any muscular artifact during EEG. The room used to capture the signal was sound-protected. To perform data acquisition, we reduced brightness to minimize sensory interference during the experiment. The experimental design was divided into three parts: first, we submitted the participants to an EEG record, resting for 3 minutes with eyes open; then, they executed the paradigm (explained below) simultaneously with the EEG record; and after the task, they were submitted to another EEG record at rest for 3 minute, with eyes open.

The oddball paradigm²⁸ consists of two stimuli presented randomly, one of which occurs infrequently. The subjects must discriminate target (infrequent) from nontarget or standard stimuli (frequent). In the present experiment, target stimuli corresponded to a square, and nontarget stimulus to a circle. We instructed subjects to keep their eyes fixed on the center of the screen and respond as quickly as possible to the target stimulus by pressing a button on a joystick (Quickshot Crystal CS4281). Each stimulus lasted 2.5 seconds, with the same interval time between stimuli, with the screen turned off. We submitted each participant to six blocks of ten trials. In other words, the square was presented ten times in each stage.

Electroencephalography data acquisition

We recorded the signal acquisition using the 20-channel Braintech-3000 EEG system (EMSA Medical Instruments, Rio de Janeiro, RJ, Brazil). Additionally, two more electrodes were positioned on the earlobes, set as reference points, yielding 20 monopole derivations (using Fpz as a ground electrode). The signal corresponding to each EEG derivation resulted from the electric potential difference between each electrode and the preestablished reference (earlobes). We calculated the impedance levels of each EEG electrode and kept them

below 5 k Ω . The data acquired had a total amplitude of less than 100 μ V. The EEG signal was amplified, with a gain of 22,000, analogically filtered between 0.1 (high-pass) and 100 Hz (low-pass), and sampled at 240 Hz, Notch (60 Hz).

Electroencephalography data processing

Visual inspection and independent component analysis (ICA) were used to quantify reference-free data by removing possible sources of task-induced artifacts. We excluded data from individual electrodes exhibiting loss of contact with the scalp or high impedances (> 5 k Ω), as well as data from single-trial epochs that showed excessive movement artifact ($\pm 100 \mu$ V). Then, ICA was applied to identify and remove any artifacts after the initial visual inspection. Independent components resembling an eye blink or muscle artifact were also removed. The remaining components were then projected back onto the scalp electrodes by multiplying the input data by the inverse matrix of the spatial filter coefficients, derived from ICA using established procedures. This data were then reinspected for residual artifacts using the rejection criteria described above. We reduced quantitative EEG parameters to 4 seconds before the oddball paradigm joystick button press, that is, the moment preceding index finger movement.

Statistical analysis

The Levene and Shapiro-Wilk tests previously verified the normality and homoscedasticity of the data. Afterward, a two-way analysis of variance (ANOVA) was used between the group and the moments, aiming to explore the interaction. Consequently, a repeated-measures ANOVA was applied to identify the EEG- β power differences for moments within each group. We used the Mauchly test criteria to evaluate the sphericity hypothesis and the Greenhouse-Geisser ($G\epsilon$) procedure to correct freedom degrees. We analyzed the interactions with multiple comparisons by the Bonferroni post hoc. We estimated the size effect as partial squared eta (η^2p), and calculated the statistical power and the 95% confidence interval for dependent variables. We interpreted the magnitude of the effect by using the recommendations suggested by Hopkins et al.: 0.0 = trivial; 0.2 = small; 0.6 = moderate; 1.2 = large; 2.0 = very large; and 4.0 = almost perfect.²⁹ To detect the real difference in the population, we interpreted a statistical power from 0.8 to 0.9 as high power [R].³⁰ Thus, the p -value was divided by the number of cortical regions analyzed, from a total of 7 ($p = 0.0071$). The probability of 5% was adopted in all analyses ($p \leq 0.05$).

RESULTS

There was an interaction between the group and moment factors for Fp1 ($F_{(2,374)} = 22.041$; $p < 0.001$; $\eta^2p = 0.105$; power = 99.9%; ► **Figure 1A**). The Mauchly test indicated that sphericity was considered ($p = 0.140$). The post hoc test showed that, in the group of nonexercisers, resting time 1 was different from prestimulus ($p < 0.001$) and resting time 2 ($p < 0.001$). For practitioners, resting time 1 was different from prestimulus ($p = 0.027$) and resting time 2

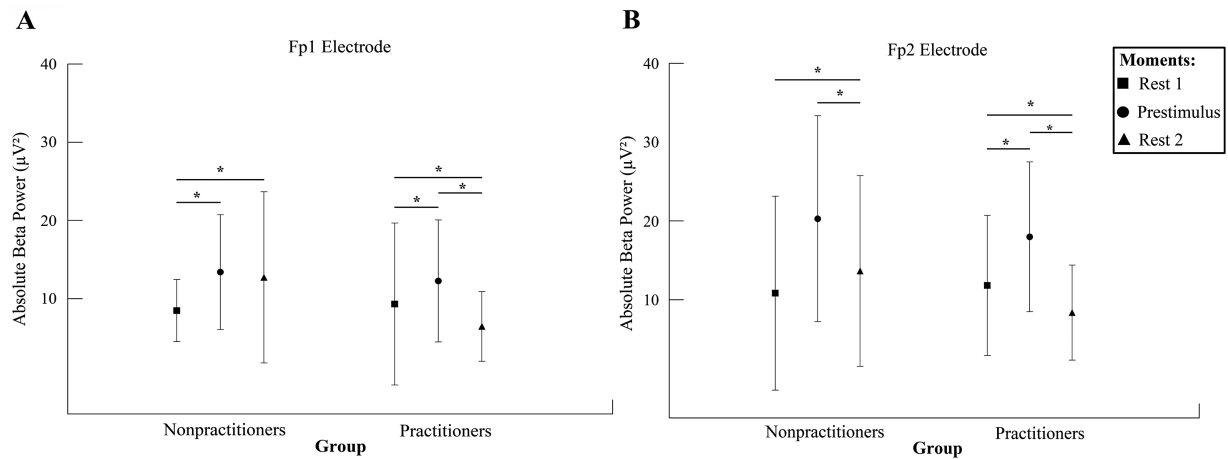


Figure 1 The mean and standard deviation of absolute β power (μV^2). (A) Left frontopolar cortex (Fp1) interaction between group and moments (nonpractitioners vs. practitioners vs. rest 1 vs. prestimulus vs. rest 2; $p < 0.001$). The repeated measures ANOVA demonstrated a significant difference for a moment rest 2 compared with moment prestimulus between groups ($p < 0.001$). (B) The right frontopolar cortex (Fp2) interaction between group and moments (nonpractitioners vs. practitioners vs. rest 1 vs. prestimulus vs. rest 2; $p < 0.001$). The repeated measures ANOVA demonstrated a significant difference for prestimulus compared with rest 1, and for rest 2 compared with rest 1, between groups ($p < 0.001$). Bonferroni post hoc comparisons are highlighted by asterisks.

($p = 0.001$); also, prestimulus was different from resting time 2 ($p < 0.001$).

Concerning Fp2, we saw an interaction between the factors group and time ($F_{(2,342)} = 7.392$; $p = 0.001$; $n2p = 0.041$; power = 93.9%; ►Figure 1B). The Mauchly test indicated that sphericity was considered ($p = 0.452$). The post hoc test showed that, in the group of nonexercisers, resting time 1 was different from resting time 2 ($p < 0.001$); and prestimulus time was different from resting time 2 ($p < 0.001$). For practitioners, resting time 1 was different from prestimulus ($p < 0.001$) and resting time 2 ($p < 0.001$); also, prestimulus was different from resting time 2 ($p < 0.001$).

We found an interaction between the group and moment factors for F7 ($F_{(1,920, 359,110)} = 42.345$; $p < 0.001$;

$n2p = 0.185$; power = 99.9%; ►Figure 2A). The Mauchly test indicated that sphericity was violated ($p = 0.019$). Therefore, the degrees of freedom were adjusted ($\epsilon = 0.960$). The post hoc test showed that, in the group of nonexercisers, resting time 1 was different from prestimulus ($p < 0.001$) and resting time 2 ($p < 0.001$). For practitioners, resting time 1 was different from prestimulus ($p = 0.027$) and resting time 2 ($p = 0.001$); also, prestimulus was different from resting time 2 ($p < 0.001$).

There was also an interaction between the factors group and time for F8 ($F_{[1.764, 333.468]} = 33.388$; $p < 0.001$; $n2p = 0.150$; power = 99.9%; ►Figure 2B). The Mauchly test indicated that sphericity was violated ($p < 0.001$). Therefore, the degrees of freedom were adjusted ($\epsilon = 0.882$). The post hoc test showed that, in the group of nonpractitioners,

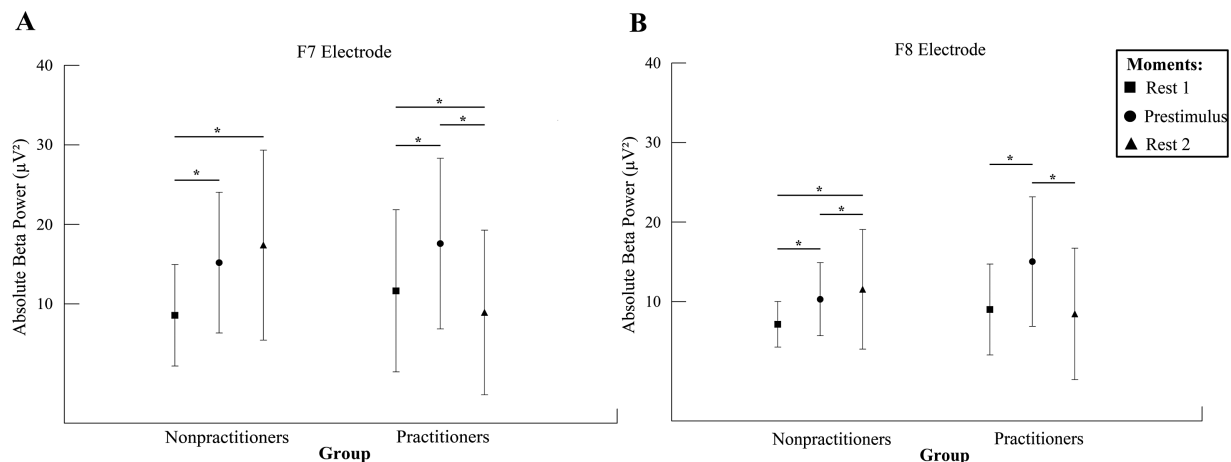


Figure 2 The mean and standard deviation of absolute β power (μV^2). (A) Left inferior prefrontal gyrus (F7) interaction between groups and moments (nonpractitioners vs. practitioners vs. rest 1 vs. prestimulus vs. rest 2; $p < 0.001$). The repeated measures ANOVA demonstrated a significant difference for prestimulus compared with rest 2, and a significant difference for rest 2 compared with rest 1, between groups ($p < 0.001$). (B) The right prefrontal gyrus (F8) interaction between groups and moments (nonpractitioners vs. practitioners vs. rest 1 vs. prestimulus vs. rest 2; $p < 0.001$). The repeated measures ANOVA demonstrated a significant difference for rest 2 compared with prestimulus ($p < 0.001$). The Bonferroni post hoc comparisons are highlighted by asterisks.

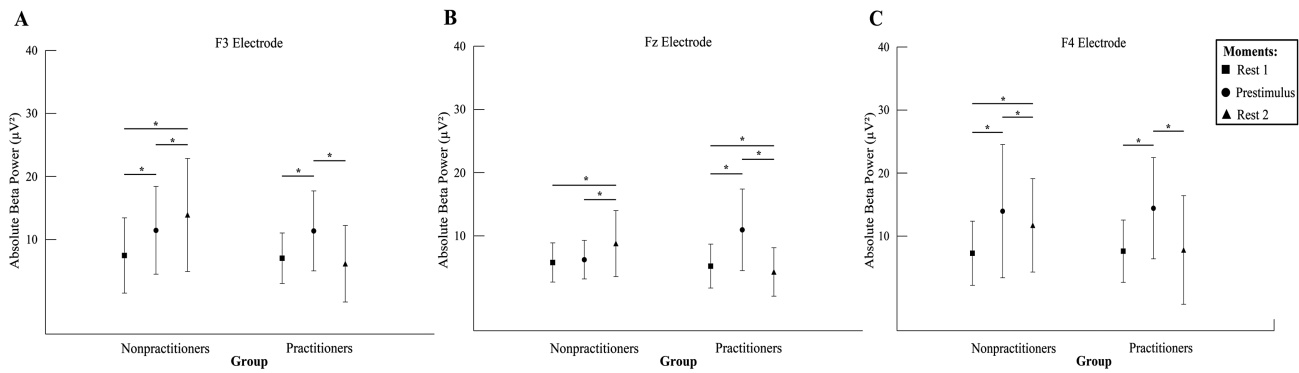


Figure 3 The mean and standard deviation of absolute β power (μV^2). (A) Left anterior frontal cortex (F3) interaction between group and moments (nonpractitioners vs. practitioners vs. rest 1 vs. prestimulus vs. rest 2; $p < 0.001$). The repeated measures ANOVA demonstrated a significant difference for rest 2 compared with prestimulus between groups ($p < 0.001$). (B) The midline anterior frontal cortex (Fz) interaction between group and moments (nonpractitioners vs. practitioners vs. rest 1 vs. prestimulus vs. rest 2; $p < 0.001$). The repeated measures ANOVA demonstrated a significant difference for prestimulus compared with rest 2 ($p < 0.038$), and a significant difference for rest 2 compared with rest 1 between groups ($p < 0.007$). (C) The right anterior frontal cortex (F4) interaction between group and moments (nonpractitioners vs. practitioners vs. rest 1 vs. prestimulus vs. rest 2; $p < 0.001$). The repeated measures ANOVA demonstrated a significant difference for prestimulus compared with rest 2, between groups ($p < 0.001$). Bonferroni post hoc comparisons are highlighted by asterisks.

resting moment 1 was different from prestimulus ($p < 0.001$) and resting moment 2 ($p < 0.001$); and prestimulus moment was different from resting moment 2 ($p = 0.038$). For practitioners, resting time 1 was different from prestimulus ($p < 0.001$); also, prestimulus was different from resting time 2 ($p < 0.001$).

We observed an interaction between the group and moment factors for F3 ($F_{(1.904, 359.831)} = 45.386$; $p < 0.001$; $n2p = 0.194$; power = 99.9%; ►Figure 3A). The Mauchly test indicated that sphericity was violated ($p = 0.008$), so the degrees of freedom were adjusted ($\epsilon = 0.952$). The post hoc test showed that, in the group of nonpractitioners, resting time 1 was different from prestimulus ($p < 0.001$) and resting time 2 ($p < 0.001$); also, pre-stimulus was different from resting time 2 ($p = 0.007$). For practitioners, resting time 1 was different from prestimulus ($p < 0.001$); also, prestimulus was different from resting time 2 ($p < 0.001$).

Regarding Fz, there was an interaction between the factors group and time ($F_{(1.573, 297.313)} = 106.211$; $p < 0.001$; $n2p = 0.360$; power = 99.9%; ►Figure 3B). The Mauchly test indicated that sphericity was violated ($p < 0.001$), so the degrees of freedom were adjusted ($\epsilon = 0.787$). The post hoc test showed that, in the group of nonexercisers, resting time 1 was different from resting time 2 ($p < 0.001$); also, prestimulus was different from resting time 2 ($p < 0.001$). For practitioners, resting time 1 was different from prestimulus ($p < 0.001$) and resting time 2 ($p = 0.007$); also, prestimulus was different from resting time 2 ($p = 0.038$).

Concerning F4, there was an interaction between the group and moment factors ($F_{(2.378)} = 10.397$; $p < 0.001$; $n2p = 0.052$; power = 98.8%; ►Figure 3C). The Mauchly test indicated that sphericity was considered ($p = 0.051$). The post hoc test showed that, in the group of nonexercisers, resting time 1 was different from prestimulus ($p < 0.001$) and resting time 2 ($p < 0.001$); also, pre-stimulus was different from resting time 2 ($p = 0.023$). For practitioners, resting

time 1 was different from prestimulus ($p = 0.027$); also, prestimulus was different from resting time 2 ($p < 0.001$).

DISCUSSION

The differences in absolute β power in the prefrontal and frontal regions before, in preparation for, and after the oddball paradigm in nonexercisers and exercisers were analyzed. The investigation of these areas is especially relevant due to their involvement with cognitive functions and motor aspects.³¹ We expected a decrease in β , related to the effect of physical conditioning according to the principle of neural efficiency. The results were in line with our hypothesis in the three subregions analyzed: the anterior prefrontal cortex (Fp1 and Fp2), the inferior prefrontal gyrus (F7 and F8), and the frontal eye field (F3, Fz, and F4).

The anterior prefrontal cortex (or frontopolar cortex), located anatomically over the anterior frontal region of the cortex (Brodmann areas 9 and 10), has been associated with complex executive functions that play an important role in task organization, planning, motor representation, and decision-making.^{32,33} Our results showed a significant interaction between groups and times for both electrodes (Fp1 and Fp2).

In this sense, the subsequent analysis for Fp1 showed that the differences between the groups are related to resting times 1 and 2, and the prestimulus and resting time 2. The decrease in β observed for the group of exercisers, compared with the nonexercisers, may suggest the idea of neural efficiency in the frontopolar cortex region after a task.³⁴ A recent study compared β EEG in groups of physical activity practitioners and nonpractitioners during a time-estimation task.³⁵ The results showed lower β power for the practitioners. The authors suggested that lower β and better performance in the time estimation task may indicate maintenance of attention and neural efficiency. Additionally, a meta-analysis investigated the effects of physical training on

executive functions in adults,³⁶ with the results reporting benefits after physical training, suggesting that training has an enhancing effect on cognition.

Concerning Fp2, further analysis showed that the differences between groups were related to resting time 1 and prestimulus, as well as resting times 1 and 2. The results reveal the mutual participation of the frontopolar cortex during the experiment and reflect an efficient oscillatory mode for practitioners, related to greater aptitude after meeting the demands of the attentional paradigm, represented by a greater state of cortical deactivation. This difference may represent practitioners' more efficient neural networks, which are involved in allocating attention from the start of the experiment.⁶

These findings align with previous works highlighting differences in cortical activity underlying physical training. A previous study investigated the speed of information processing in athletes compared with a control group.³⁷ The results indicated the amount of practice allowed for the development of preparatory activities, which may suggest that the β dynamics indicate that the effects of physical exercise are correlated with cognitive improvement, meaning that tasks set by internal factors are associated with a cognitive effort dependent on executive functions, reflected by β activity.

The inferior prefrontal gyrus has been associated with language,³⁸ mnemonic processes,³⁹ and action observation.⁴⁰ Previous studies have indicated the involvement of this area in processing semantic language and nonverbal attributes.⁴¹ Our results demonstrated a significant interaction between the groups and time points for both electrodes (F7 and F8).

We also observed a decrease in β in the group of practitioners within the left inferior prefrontal gyrus (F7). This result suggests less cortical activation in the identification, analysis, and attention to information during the experimental paradigm, especially in the hemisphere characterized by analytical processes.⁴² The decrease in β can be understood as efficiency during the experimental task, that is, reduced effort and, consequently, a deactivation. A recent study suggested that a single session of moderate-intensity aerobic exercise improves performance in mnemonic discrimination tasks in healthy individuals.⁴³

As for F8, the subsequent analysis showed that the differences between groups are related to resting times 1 and 2, along with prestimulus and resting time 2. The dynamics of F8 can be explained by the behavior observed in prestimulus and resting time 2. In contrast, the cortical deactivation observed for the group of exercisers can be understood as an efficiency, that is, a decrease in power over the region after the experimental task.⁴⁴ Thus, our findings represent an efficient oscillatory β mode related to a greater aptitude for the experimental paradigm's demands, represented by cortical deactivation in the exercisers.

Located anatomically in the premotor cortex (Brodmann area 8), the anterior frontal cortex plays a complex role in various higher functions, such as planning, sustained

attention, and motor learning.^{45,46} Additionally, this region plays an important role in planning and controlling saccadic eye movements.⁴⁷ Our results showed a significant interaction between groups and times for both electrodes (F3, Fz, and F4).

The analysis of the interaction in F3 revealed that the differences between groups are related to resting times 1 and 2, as well as prestimulus and resting time 2. The results observed for the group of practitioners can be understood as a state close to automaticity during the experimental task, favoring energy saving, as observed by the decrease in β .

Decreases in β have been observed in the sensorimotor and frontal areas in young adults after a motor task, probably indicating automaticity in motor control,^{48,49} reflecting β 's functional role in motor learning processes. A previous study observed a greater increase in β among sedentary individuals compared with the athletic group, suggesting that active individuals were more successful at maintaining focus under stress compared with sedentary individuals.⁵⁰

Concerning Fz, further analysis has shown that differences between groups are related across all three moments. The dynamics observed for the exercising group can be explained by sophisticated cortical redistribution, where cortical areas not relevant to the task are disregarded, that is, energy saving.¹⁸ A recent study proposed that exercise involves excitation mechanisms through various neurotransmitter systems to facilitate the processing of implicit information, which deactivates higher-order functions of the cortex to prevent useless processes from compromising the implicit system's functioning during motor execution.¹⁶

Finally, the subsequent analysis in F4 showed that the differences between groups were related at resting times 1 and 2. The results may indicate that the group of practitioners automated the reactions between visual stimulus and imposed response, meaning there was a decrease in β to its initial state after the task.⁵¹ A cross-sectional study showed a relationship between aerobic fitness and neural rhythms in a visuospatial attention task among young adults of high- and low-levels of fitness. The high-fitness participants had faster reaction times and greater β during target processing. These findings indicated that physical fitness may be positively correlated to greater visuospatial attention capacity by modulating attentional processes.⁵²

Limitations of this study

- Initially, the electroencephalographic analysis was limited to only 20 channels, providing an adequate spatial sample for future analysis.
- Our findings are quite discrete, suggesting that claims regarding the significance of physical exercise on cognitive functions should be more moderate, and that further analyses with other variables are needed.
- Based on the literature indicating physical exercise as a neuroenhancer, it is essential to consider the use of other protocols in future studies. These may include exploring

the potential effects related to cognitive events before and after physical training.

In conclusion, this study investigated the electrophysiological changes influenced by physical exercise during an attentional task. Our findings provide new evidence on the relationship between physical exercise and cortical activity. Thus, we conclude that ECG correlates of the prefrontal and frontal regions promote understanding of the cognitive processes underlying physical exercise and can be used in future interventions and posttraining extrinsic feedback.

Authors' Contributions

MM: formal analysis, visualization, and writing – original draft; RF, GZ, CA: validation; AV: writing – review & editing; EC: validation; EN: conceptualization, formal analysis, visualization, and writing – original draft; MG, MO: validation; RV: data curation, investigation, validation, writing – original draft, and writing – review & editing; ST, HB: validation; MC: formal analysis, methodology, software, and supervision; BV: conceptualization, methodology, project administration, and supervision; PR: conceptualization, formal analysis, methodology, project administration, supervision, visualization, and writing – review & editing.

Conflict of Interest

The authors have no conflict of interest to declare.

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