REVISTA NEUROCIÊNCIAS

Original

Electrophysiological effects of kinesthetic motor imagery in visuomotor task performance

Efeitos eletrofisiológicos da imagética cinestésica motora no desempenho de tarefas visomotoras

Efectos electrofisiológicos de las imágenes motoras cinestésicas en el rendimiento de tareas visomotoras

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Resumo

Introdução. O estudo do funcionamento cerebral durante a tarefa visomotora pode contribuir para o esclarecimento dos processos de aprendizagem que envolvem o funcionamento cognitivo, a atenção e o comportamento motor. Nesse contexto, a imagética é parte fundamental do treinamento de tiro de alto rendimento. As mudanças eletrofisiológicas na potência absoluta de alfa durante o tiro com pistola antes e após uma intervenção de imagética motora foram examinadas comparando especialistas com atiradores iniciantes. **Método**. Trata-se de um *estudo quase-experimental* com 19 sujeitos (25-37 anos). A atividade eletrofisiológica cerebral foi estimada como potência alfa absoluta durante uma tarefa de tiro com pistola de ar autocadenciada antes e após a intervenção de treinamento de imagética motora cinestésica (IMK). As análises foram realizadas por ANOVA *two-way* seguida do teste t de Student. **Resultados**. Houve interações e efeitos principais em todas as áreas para ambos os grupos. Os resultados indicaram que a intervenção de treinamento do IMK induziu mudanças nas atividades corticais relacionadas à melhora das funções executivas, tais como: planejamento de ações, flexibilidade cognitiva, mudança de planos e decisões e diferentes formas de armazenamento de informações que contribuem para o aumento do desempenho no tiro.

Unitermos. Imagética motora; eletroencefalografia; potência absoluta; neurociência; comportamento motor

Abstract

Introduction. The study of brain functioning during visuomotor task can contribute to clarifying learning processes involving cognitive functioning, attention and motor behavior. In this context, imagery is a fundamental part of high-performance shooting training. Electrophysiological changes in absolute alpha power during pistol shooting before and after a motor imagery intervention were examined by comparing experts with novice shooters. **Method**. This was a *quasi*-experimental study with 19 subjects (25-37 years old). Electrophysiological brain activity was estimated as absolute alpha power during a self-paced air pistol shooting task before and after kinesthetic motor imagery (KMI) training intervention. Analyses were performed using two-way ANOVA followed by Student´s t-test. **Results**. There were interactions and main effects in all areas for both groups. The results indicated that the

KMI training intervention induced cortical activity changes related to improving in executive functions, such as: action planning, cognitive flexibility, change of plans and decisions, and different forms of information storage that contribute to increased shooting performance.
Keywords. Motor imagery; electroencephalography; absolute power; neuroscience; motor behavior

Resumen

Introducción. El estudio del funcionamiento cerebral durante la tarea visomotora puede contribuir al esclarecimiento de los procesos de aprendizaje que involucran el funcionamiento cognitivo, la atención y la conducta motora. En este contexto, las imágenes son una parte fundamental del entrenamiento de tiro de alto rendimiento. Se examinaron los cambios electrofisiológicos en la potencia alfa absoluta durante el tiro con pistola antes y después de una intervención de imágenes motoras comparando a los expertos con los tiradores novatos. **Método**. Se trata de un estudio *cuasi-experimental* con 19 sujetos (25-37 años). La actividad cerebral electrofisiológica se estimó como potencia alfa absoluta durante una tarea de tiro con pistola de aire a su propio ritmo antes y después de la intervención de entrenamiento de imágenes motoras cinestésicas (IMC). Los análisis se realizaron mediante ANOVA de dos vías seguido de la prueba t de Student. **Resultados**. Hubo interacciones y efectos principales en todas las áreas para ambos grupos. Los resultados indicaron que la intervención de entrenamiento KMI indujo cambios en la actividad cortical relacionados con la mejora de las funciones ejecutivas, tales como: planificación de acciones, flexibilidad cognitiva, cambio de planes y decisiones, y diferentes formas de almacenamiento de información que contribuyen a aumentar el rendimiento de tiro.
Palabras clave. Imágenes motoras; electroencefalografía; potencia absoluta; neurociencia; comportamiento motor

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Conflict of interest: no Received in: 03/14/2024 Accepted in: 05/22/2024

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INTRODUCTION

Good performance in visuomotor task as target shooting requires focused attention, discipline, reasoning, initiative together with physical and psychological balance. Moreover, it is crucial to achieve an optimized visual frame in the aiming period and maintain it up to the trigger pull[1]. Hence, it involves cognitive, psychological, and motor aspects related to body position, weapon position, target aiming, and focused attention associated with precise mental states such as calm, arousal, and attention. Those states can be observed according to specific frequency bands of brain oscillation[2,3]. There are functional relationships among parietal, temporal, and occipital cortical activity at the alpha band, which were observed in experts and novice air pistol shooters with different brain activation according to areas[2], indicating that practice can lead to changes in brain function organization[2,4].

To observe cortical activity, it is fundamental to examine the alpha rhythms because the neural spiking rates in cortex decrease when the alpha-power waves increase[5], i.e., the higher the frequency of alpha waves, the lower cortical activity in a given brain region. A study comparing novices with elite rifle shooters have found that the expert shooters presented a higher increase in alpha power in the left hemisphere and a higher decrease in the right hemisphere during the aiming period[6]. After 14 weeks of learning pistol shooting, novices showed an increase in alpha-power in the left-temporal region (T3)[4,7-9].

In neuroscience, mental training technique refers to motor imagery, which may benefit patients' functional recovery and high-performance athletes of several sports modalities as well[9,10] because motor imagery (MI) and motor action involve overlapping of brain systems[8]. Thus, MI may activate brain regions related to real motor movement[8]. Therefore, it is expected that motor imagery enhances motor skill performance, making it an important strategy for both sport performance and rehabilitation of patients[11,12]. A recent systematic review concluded that the causal relationship between MI and sports performance is not yet clear yet and further experimental or longitudinal studies are required[9]. The aim of this study was to examine the electrophysiological changes in absolute alpha power (AAP) during a complete experimental protocol of pistol shooting competition (visuomotor task), which is a self-paced task, before and after a kinesthetic motor imagery (KMI) intervention, comparing experts with novice shooters. The hypothesis was that KMI training could promote changes in cortical activities favoring cognitive processes related to performance.

METHOD

Study design and sample

This was a *quasi*-experimental study with a convenience sample composed of students from the Federal University of Rio de Janeiro and the Brazilian Army School of Physical Education. The inclusion criteria were to be aged between 25 and 37 years, and to be apparently healthy. Exclusion criteria were as follows: 1) Presenting a type of cognitive deficit; 2) Using any medication or psychoactive substance in the time of the experiment; 3) Left eye dominance; and 4) Left hand dominance.

Twenty-four individuals of both sexes were invited to the study, after applying the exclusion criteria, five were withdraw. Thus, 19 individuals from both sexes participated in the study and were allocated into two groups: expert shooters and novice shooters. For an 80% sample size power ($d=0.50$ effect width, $\alpha=0.05$ type I error, $\beta=0.20$ type II error) with expected changes in cortical activities among experts of 86%.

This study was approved by the Research Ethics Committee of the Federal University of Rio de Janeiro, Psychiatric Institute (CAAE 4587.3215.6.0000.5263). All volunteers signed the Free Informed Consent Form (FICF).

Procedure

The main outcome was electrophysiological changes in AAP during a self-paced air pistol shooting task. The secondary outcome was performance in shooting (behavioral variable). The exposure variable was the intervention with MI.

Electrophysiological variable: absolute alpha power (AAP)

AAP (8-12 Hz) was assessed to evaluate the cortical activity alterations produced by the KMI intervention during the self-paced sensory-motor task (target shot with compressed air pistol). Specifically, AAP measurements were used to observe possible cortical changes through energy intensity in the electrodes. We examined the following cortical areas: frontal (electrodes Fp1, Fp2, F7, F8, F3, Fz, and F4), temporal (electrodes T3, T4, T5, and T6), central (electrodes C3, Cz, and C4), parietal (electrodes P3, Pz and P4) and occipital cortexes (electrodes O1, Oz, and O2).

Behavioral variables – performance in target shooting

The behavioral variables examined were the components of shooting performance: total score; the amount of X scores (central ten); ten scores (those noncentral ten); and dispersion of shots. Dispersion is one of the main shooting performance indicators expressing accuracy and constancy of the shooter performance, thus, we also used the mean of radius of the dispersion of the shots in the target. Those variables were taken during self-paced shooting task and analyzed using the computational system TargetScan® version 5.8.2 – Deep Scoring Ltd. England.

Experimental procedures

The experiment took place at the Brazilian Army School of Physical Education (BASPE), in a soundproof laboratory, which had the appropriate footage for the experiment (7x5m), with electronic equipment (electroencephalograph, computer and recording system connected to the EEG registering the moment of each shot). The participants were divided into two groups: expert shooters (ES) and novice shooters (NS). The ES group comprised individuals experienced in practice and/or competition of target shooting, and the NS group comprised people who has never had any type of contact with target shooting (debutants).

Paradigm

The experiment consisted of three moments: two visits to the laboratory, with an interval of 15 days in between (Figure 1). At the first visit, the FICF was signed by the participants, and the following initial evaluations were carried out: a) An inventory of medical and neuropsychiatric conditions, composed of questions about conditions related to: visual difficulties, neurological, motor, and/or psychiatric problems; b) The Edinburgh Inventory Implementation was used to verify the laterality predominance of the participants; c) The Vividness of Visual Imagery Questionnaire (VVIQ) to assess the ability of sharpness and visual image[13]. Then, specific instructions about how to aim the target and proceed the shooting were taught to the participant, followed by two warm up blocks and five scoring blocks. Each block composed by four shots. The task was performed using special prepared shooting glasses (Figure 2). For full information about signal acquisition, paradigm, and task, see Silva *et al*.[12].

Intervention: kinesthetic motor imagery (KMI) training

The intervention was KMI training, which specific instructions were as follows: The participant should imagine all preparative procedures before the scoring shooting blocks. Then, should visualize him/herself proceeding the scoring shooting blocks comprehending the preparation of each shot, aiming time, and pulling the trigger of each one with the image of the perfect sight alignment (Figure 3) and proceeding the follow-through (the after shot subsequent perfect sight alignment). This activity was proposed to be performed daily for 15 days. After that period, the participant returned to the laboratory for a second visit.

Figure 1. Study paradigm.

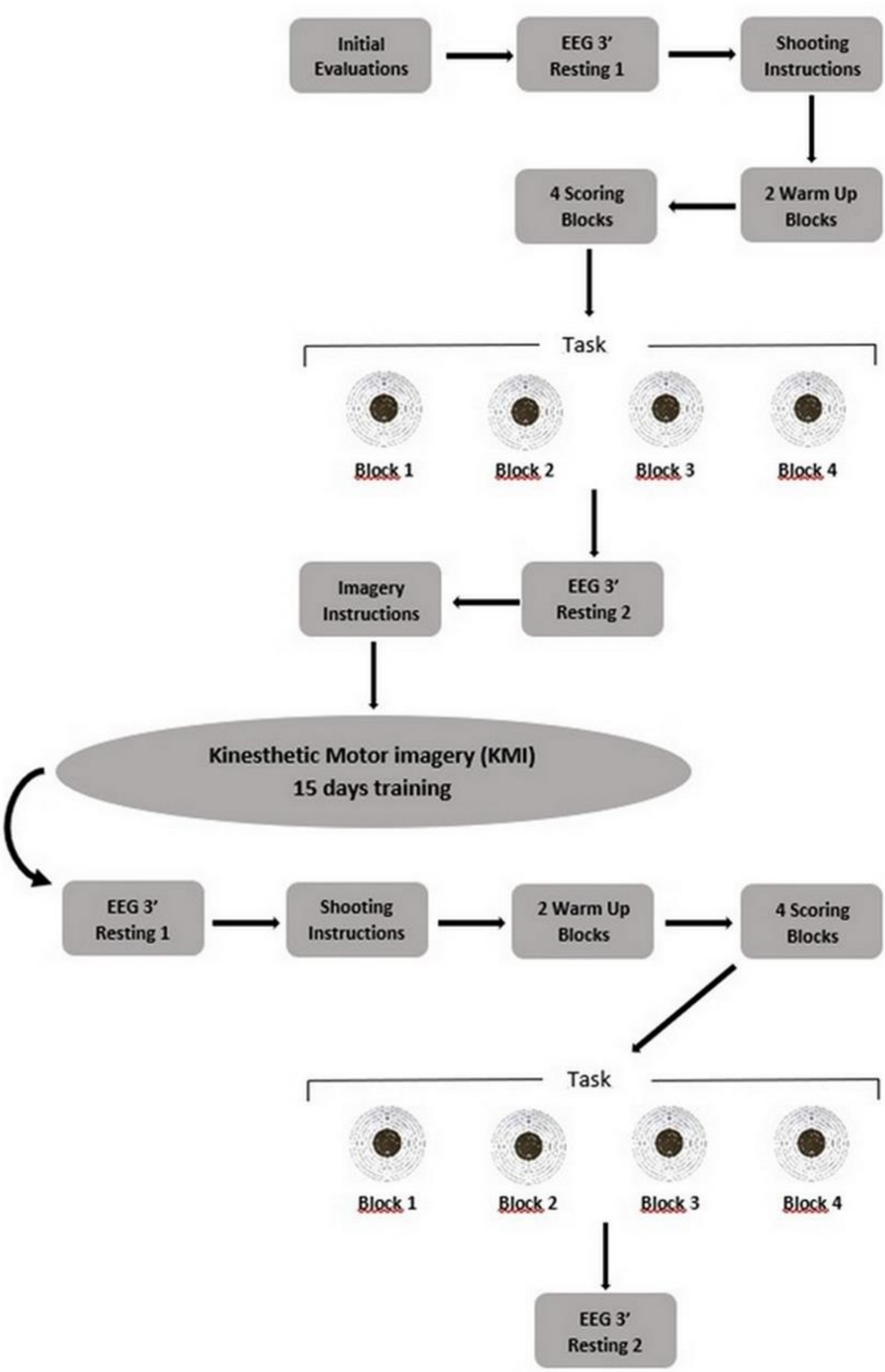


Figure 2. Experiment participant.

Figure 3. Perfect Sight.

Statistical analysis

To examine the cortical activity differences between the groups (ES/NS) and according to moments, pre- and post-intervention (main effect), we used two-way ANOVA. The *post hoc* test used was paired *Student's t*-test. To compare the performance, the following technical shooting data were examined: total dispersion, scores 10, score X (central ten), and total score according to groups before and after intervention. The paired Student's *t*-test and mean differences were used. For all analyses, the confidence level was 95%.

RESULTS

From the 24 invited to participate in the study, four were withdrawn for the exclusion criteria: four for being predominantly left-handed and one for being out of the age range. Thus, 19 individuals (11 NS and 08 ES) participated in the study, 94% were male and the mean age was 32±5.4 years. Adherence to KMI training was significantly higher in the NS (mean 9.91±3.22) comparing with ES (mean 6.91±2.07; p=0.012).

Behavioral results

Regarding behavioral results, there was a significant difference in performance for both groups before and after training with KMI (p<0.05) and no interaction in both comparison groups (ES and NS) and moments (pre- and post-intervention). There was a significant increase in shooting performance at the post-intervention moment in both groups. In ES group the total score increase was higher than NS (p=0.03; Table 1).

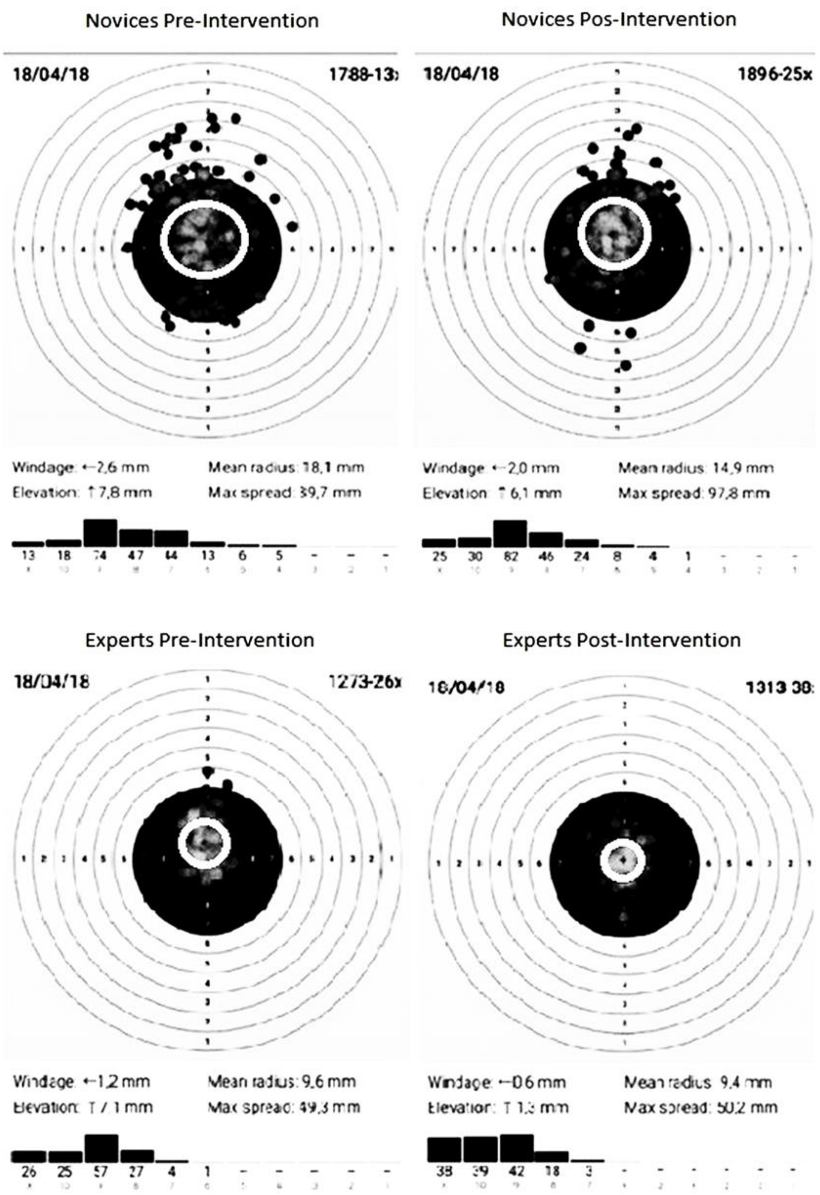
The graphic results of performance are exhibited in Figure 4 exhibiting the mean radius of the shooting dispersion in the target into the white circles.

Table1. Performance in target shooting in pre- and post-intervention with kinesthetic motor imagery (KMI) training according to levels of expertise (N=19).

Performance[a]	**Experts Shooters (ES)**			**Novices Shooters (NS)**		
	Pre	***Post***	**Dif.**	***Pre***	***Post***	**Dif.**
Scores 10	25	39	**14**	18	30	**12**
Scores X	18	30	**12**	13	25	**12**
Mean of radius	9.6	9.4	**-0.2**	18.1	14.9	**-3.2**
Total Score	178.8	189.6	**10.8**	127.3	131.3	**4.0**

[a]**Performance**: number of impacts on the target according performance attributes; **Pre**: moment pre-intervention with kinesthetic motor imagery (KMI) training. **Post**: moment post KMI intervention; **Dif**: scores' difference between moments pre- and post-intervention; **Scores X**: scores central ten. **Mean of radius**: it is the dispersion measure. Statistical significance: p-value < 0.05 indicated in bold. Results from paired Student´s t test.

Figure 4. Shooting performance before and after KMI intervention in experts and novices (n=19).



Electrophysiological results

For Fp1, Fp2, and Fpz, there was interaction only in Fp1 (p=0.004; F=9.402). There were statistically significant changes only in the ES group (p=0.000) with decreasing in AAP. In Fp2, there were no statistically significant changes according to groups and moments (p=0.061; Figure 5) and same results in Fpz (p>0.05). In F3, Fz and F4 electrodes, there was no interaction. However, in F3, there was main effect in both groups (p=0.000; F= 18.401) and moment (p=0.003; F= 8.937). In F4 (p=0.000; F=15.553) and Fz (p=0.002; F=9.341) there were main effects for group. There was interaction only on in F8 (p=0.014; F=6.056). There were statistically significant changes (p=0.000) only in the ES group, with a decrease in AAP. In F7, there was no interaction; however, there was a statistically significant difference in the ES group for moment effect (p=0.026; F=4.950).

In T3 (p=0.010; F=6.699) and T4 (p=0.001; F=10.755), and T5 (p=0.003; F=8.631) and T6 (p=0.019; F=5.252), additional analysis (*t-test*) of the interaction revealed statistically significant changes only in the ES group (p=0.000), with decreased AAP (Figure 6).

In C3, C4, and Cz, there was interaction only in C3 (p=0.006; F=7.735), with a decrease in AAP. Yet, there was a significant difference for the ES group (p=0.000). In C4, no interaction was observed, however, there was a statistically significant change in the AAP according to group (p=0.055; F=3.680) and moment (p= 0.013; F=6.137). In

Cz, there were significant changes for moment (p=0.000; F=15.063; Figure 6).

Figure 5. Electrophysiological changes in absolute alpha power (AAP) in frontal cortex in expert and novice shooters (n=19).

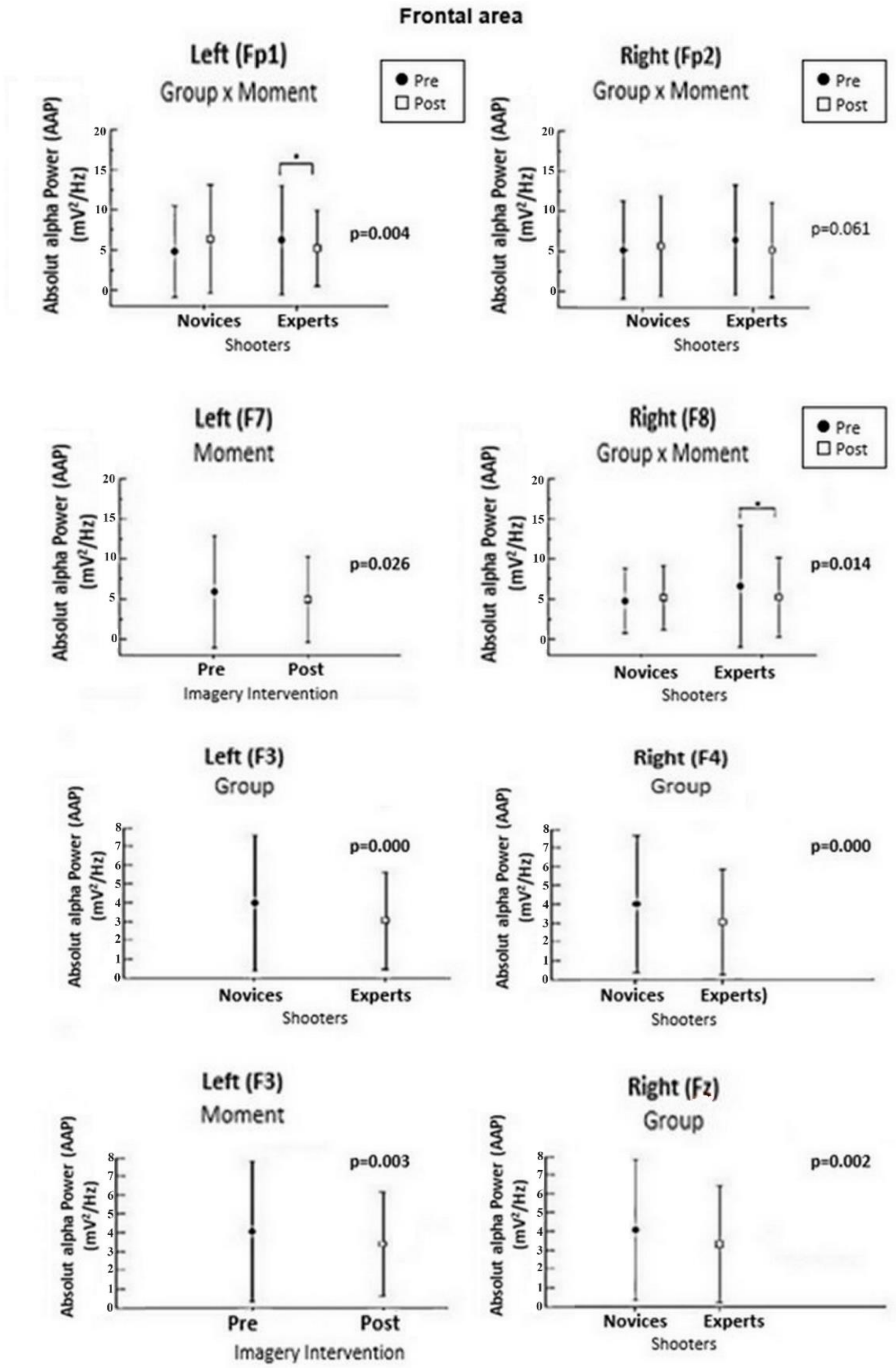
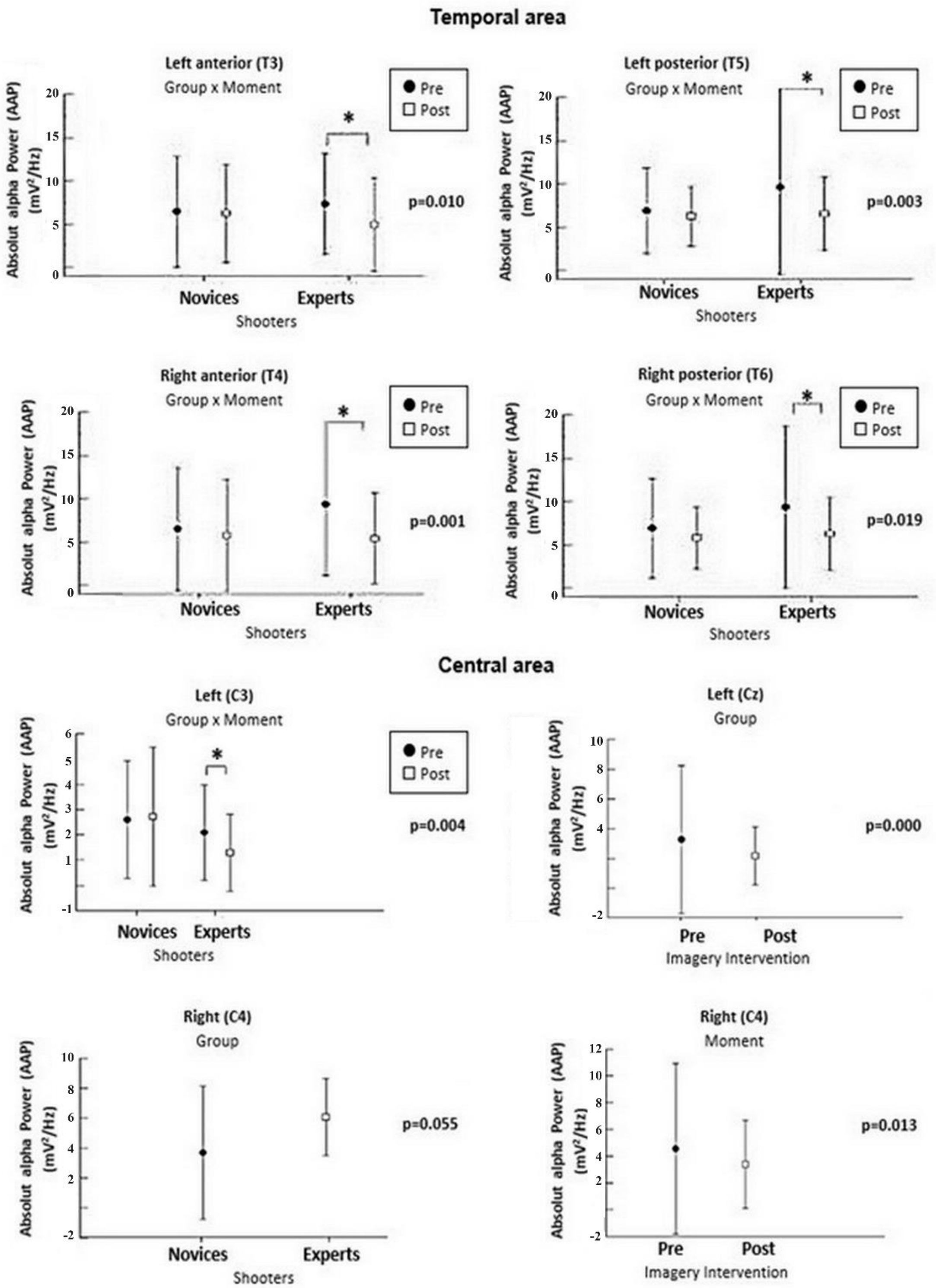


Figure 6. Electrophysiological changes in absolute alpha power (AAP) in temporal and central cortexes in expert and novice shooters (n=19).



In the parietal cortex, there were significant differences only as main effect according to group: in P3 (*p*=0.002; F=9.906), P4 (*p=0.001*; f= 11.212), and Pz) (*p*=0.000; F=1.660; Figure 7), with lower AAP in ES compared to NS.

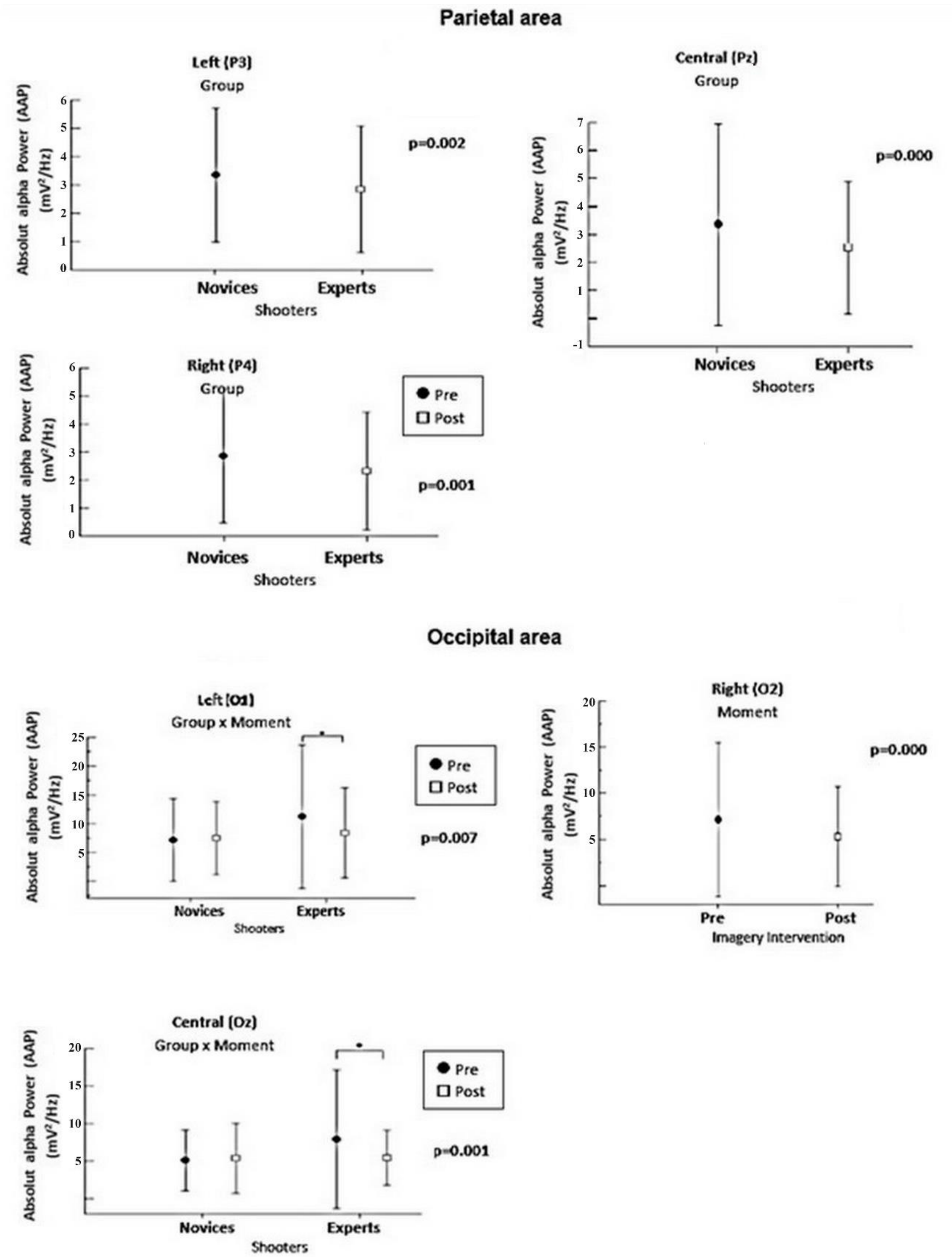
In the occipital cortex, there was interaction in O1 (*p*=0.007; F=7.373) and Oz (*p*=0.001; F=11.626), and a statistically significant decrease in AAP was observed only in the ES group (*p*=0.000). The main effect with a statistically significant change was observed in the AAP for moment (*p*=0.000; Figure 7).

DISCUSSION

Notwithstanding that the imagery training technique has been widely used among high-performance shooters for decades, we did not identify another experimental longitudinal study that investigated the effect of KMI on cortical activity during the visuomotor task in shooting. Our findings are new, and the main results were that there was interaction in the frontal, temporal, central and occipital areas. Furthermore, there were main effects in all areas according to moment and/or group. Concerning behavioral changes, the intervention with KMI promoted significant increases in shooting performance for both groups.

Results in Fp1 showed that KMI training promoted greater activation in cortical processes (decreasing in AAP) only in ES. Such findings indicate an increase in cortical activity in areas related to logical attention, decision-making, task accomplishment, and working memory[11] which was not observed in NS.

Figure 7. Electrophysiological changes in absolute alpha power (AAP) at parietal and occipital cortexes in expert and novice shooters (n=19).



In F3, the main effects were for group and moment, indicating that KMI training induced higher cortical activity (lower AAP) related to motor planning. In F4 and Fz areas the main effect was only for group, suggesting that the KMI training promoted increasing in motor planning for the upper limbs and in working memory functions. The increase in AAP in Fz was greater for the NS, a group less familiarized with the demands of the task. Such results reflect a significant and adaptive role in the organization of visuospatial and motor cortical processes during target shooting associating those cortical changes with expertise level in visuomotor task, indicating contributing to learning, which is linked to focused attention together with development of cognitive visuomotor strategies[8,14].

In F7, there was a significant decrease in total mean of AAP (Figure 5), which means that there was an increase in cortical activity related to functions of language, selective attention to speech, working memory, deductive reasoning, decision-making, and phonological processing[15,16]. These findings indicated that KMI training in shooting may improve decision-making processes together with an increase in verbal processes, which can be explained by mental training that involves the psychological technique of self-talking[17]. In F8 area, there was interaction and the difference after training with KMI only in ES. This area relates to functions of emotional expression, working memory (visuospatial), and attention[11]. To perform a good shot at the target, these attributes are highly demanded. Our findings agree with the literature because the cortical patterns of experienced and novices in distinct tasks are different[13,18].

In the temporal cortex (T3, T4, T5, and T6), there was significant decreasing in AAP only in ES (Figure 6). Mentalization can evoke self-talk action that favors the focus on goal, contributing to improve motor performance. Thus, T3 area that relates to language and verbal memory functions would be activated[19,20]. The literature suggests that self-talk can help improve attention, focus, and movement execution and promotes decreasing the undesirable effects of distraction and ego depletion[19]. This set of attitudes is usually higher used by the experienced individuals in comparison with beginners because practice leads to better distributed cortical activity to save brain energy[21], which explains the decrease in AAP. The exact functions of the right medial temporal area (T4) that associate with emotional memory related to visuospatial functions, directly influencing the processes of focused attention and related motor behavior[15,22-24], which are fundamental factors for visuomotor performance as shooting.

In C3, C4, and Cz, relate to sensory-receptive area for the sense of touch, proprioception and general somatosensory perception is the sensorimotor integration cortex[15]. In the present study, interaction was observed in C3, and statistically significant changes were found only in the ES group with a decrease in the AAP (Figure 6). This can be explained because that area relates to gross and fine motor control of the right upper limb, as all participants were right-handed, so the hand that held the weapon to perform the shots was the right, therefore, recruited greater cortical activity in the region; a phenomenon observed only among the experts, suggesting that the KMI training favored the improvement of technical details directly related to performance among the expert shooters, which was not observed in novices. In Cz, there was main effect for moment with a decrease in AAP. That area is associated with somatosensory, visuospatial processes, emotional memory, visual memory, mirror neurons' function, and motor execution, as well as the effects of MI training[11,15]. This result indicates that MI training led to an increase in cognitive effort to concentrate throughout the task, rescuing the memory of the best target and the best time for trigger activation (sentient-motor integration). In C4, there was main effect for group and for moment with a decrease in AAP in both groups.

In parietal cortex, there was no interaction, only main effect for group. In both groups AAP decreased in the three sites P3, Pz, P4, showing an increase in cortical activity during task performance (Figure 7). In line with these findings, it was observed a decrease in AAP in P3 during the preparation of movement in healthy individuals[25]. For motor planning the parietal cortex uses visual and proprioceptive information, being responsible for the initiation and sensory-motor orientation, and for the motor preparation of limbs for handling objects[16,18].

In the occipital cortex (O1, O2 e Oz), there was interaction in O1 and Oz, only in ES, with a decrease in AAP (increased activity; Figure 7). This area is involved in the processing of visual and visuospatial information and has functions in mental imaging tasks, being related to processes of spatial orientation, frequency, size, color and forma present in visual space[15]. Furthermore, each lateral area of the occipital lobe processes visual information from the eye on the opposite side of the visual field. Therefore, our findings that showed statistically significant results only for the left occipital area (O1) and not for the right respective area (O2), can be explained because the shooters had as director eye the right eye, having the left eye vision blocked by the shooting glasses during the task.

The results of this study demonstrated statistically significant performance improvement in both groups. In terms of total score, both groups exhibited better results. Nevertheless, the ES improved their performance by 10.8 points, which was over double than NS, which improved by four points. These results highlight the fundamental relevance of the MI training for high performance in visuomotor tasks as shooting. In that context, the KMI training promoted a decrease in the lateral deviation, elevation and mean of radius (dispersion), leading to performance improvement as described (Table 1 and Figure 4). The results observed after the intervention indicated that training with KMI induced changes in mental representations of reality, improving performance levels, which are in line with previous studies[8,26-28].

The cortical activation changes related to the visuomotor task observed in the present study after intervention suggest that KMI training assisted in the generation and maintenance mental images, planning, preparation, and choice of movement[24,29,30]; moreover, there was an increase in attentional focus, all of them essential factors to performance in visuomotor tasks. In despite that the NS trained KMI more frequently comparing to ES, both groups showed better results in target. These findings indicated that for experts' lower amount of KMI training promote performance improvement comparing to novices. Furthermore, it can help to integrate the best time for trigger activation with the continuous flow of visual and proprioceptive feedback, during the aiming period, which leads to greater accuracy in shooting minimizing the regulation of each component of the process separately[9,12,15].

CONCLUSION

The aim of this study was to examine the electrophysiological changes in AAP during visuomotor task in target shooting before and after an intervention with mental training and to evaluate its effects on the performance of experienced and novice individuals in the modality. The main results showed changes in cortical activities with decreased AAP in ES, i.e., there was an increase in cortical activities in the left anterior prefrontal area (Fp1), right anterior frontal area (F8), temporal cortex (T3, T4, T5 and T6), left central area (C3), primary visual cortex (Oz) and secondary visual cortex (left occipital area - O1). These changes occurred together with statistically significant performance improvement in both groups. Further studies should examine the phenomena involved in visuomotor performance and the imagery effect to better understand brain function.

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