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Research Article

Characteristic Differences between Novices and Experts in Different Shooting Stages

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Attention is the most important psychological factor affecting shooting performance. The wavelet packet energy analysis method was used to explore the differences in EEG characteristics and brain activity between experts and novices while aiming and shooting in real shooting environments. Results show that the frontal and occipital regions of novices were more active when they were aiming, while the frontal, central, and occipital regions of experts were more active when they were shooting. Overall, the frontal, central, and occipital regions of novices were more active ($p < 0.05$), whereas for experts, it was the frontal, central, parietal, and occipital regions that were more active ($p < 0.05$). Brain activity was mainly concentrated in the left hemisphere of the brain for experts, indicating that they began to take action when aiming and had higher neural efficiency. This study can help the selection and training of personnel for typical tasks that require attention by monitoring and analyzing the EEG signals of operators of different skill levels.

1. Introduction

Shooting is a goal-directed precision task where the cognitive process involves vigilance, orientation, and exclusive attention [1, 2]. Shooting accuracy plays an important role in military combat, during emergency situations, in sporting events, and so on. As the key element in a man-gun system, the shooter needs a high degree of concentration during shooting [3]. In the man-gun system, the reaction time and accuracy of capturing a target are the main factors affecting performance. The shooting process includes three psychological states, which are noticing the target, determining the position of the target [4], and shooting. Shooting performance depends on hold control, aiming accuracy, and trigger control [2]. In order to continuously improve the overall motion and coordination, the sensory system and motor system need to work together while continuously monitoring external stimuli and flexibly switching the focus of attention [5]. In addition, the visual system must orient and process the most significant perceptual cues in order to determine distance and direction information [6], which requires functional control of central nervous system and a higher level of brain function.

Studies have shown that attention is the most important psychological factor affecting shooting performance [3, 7]; focusing attention on adequate sensory information is a key factor of shooting performance [8]. Brain function coupling is stronger in experts than in novices [9]. The cognitive load theory emphasizes that the appropriate allocation of available cognitive resources is beneficial for performance [10], and determining the psychological state of a shooter during shooting is very important for setting a psychological training plan that is suitable for their skill level [11]. Therefore, an increasing number of studies have focused on the dynamics of the cerebral cortex in order to clarify the cognitive process that occurs during the execution of skills that require a high degree of attention [12, 13].

Different shooting stages correspond to different cognitive states of brain. Electroencephalogram (EEG) can detect attention, information processing, and working memory in cognitive process [14], which has been used to investigate neural activity and cognitive processes in the brain [15, 16]. To explore the influence of visual spatial cues in the shooting process on the cerebral cortex neural networks [17], and the differences in shooting performance and neural efficiency among individuals [18], scholars have mainly used EEG coupling together with some operational psychological measurement methods, questionnaire surveys, and other comprehensive evaluation and monitoring methods [7, 19]. Results have shown that different brain regions are activated for different tasks [17] and that brain activity has a certain correlation with operation performance and neural efficiency [9, 20].

Researchers have found that long-term participation in specific competitions can improve a shooter's physical reaction speed and the efficiency of psychological decision-making, therefore, experienced athletes tend to be more efficient in decision-making tasks [21]. Some studies have especially focused on the psychophysiological differences between experts and novices [15], athletes at different technical levels were compared and their brain activities were recorded during the actual sporting events [22], which included different visual attention prompts [1]. Since brain waves and frequencies will change during different stages of shooting, it is necessary to study the main visual areas of the brain that receive visual stimuli, and then direct them to the secondary visual areas of the cortex for further processing. It is important to determine how the brain processes information to produce internal representations of external phenomena [15, 17], in order to clarify the basic mechanism for achieving the best line of sight and higher shooting efficiency [23]. Studies have proven that shooting performance is related to EEG signal amplitude and changes in the power spectrum [24]. According to the requirements of cognitive resources, other autonomic parameters of brain activity in the θ and α frequency bands were combined as an index to evaluate the learning progress and the final skill level of the subjects [25]. Studies have shown that the functional connection strengths of the α and β bands are significant features of experts and novices [14]. Changes in low frequency α in the parietal and occipital regions are related to skillful cognitive motor performance; thus α is considered to be an indicator of changes in neural responses [13].

Previous studies have been helpful for providing athletes with information on their mental states. Improvements in operational performance and integration of memory leads to an improvement in skill level [26]. Memories contain many domain-specific patterns that can be described as hierarchical organizations, allowing people to classify different problem states to determine the most appropriate solution. However, the underlying neural mechanism of behavioral differences between motor skill levels is still unclear [26], due to lack of research on the brain states corresponding to each action in the shooting process. The purpose of this study was to investigate the psychophysiological differences of shooters during different stages of shooting. Real-life shooting scenarios were executed to analyze the EEG characteristics of experts and novices during aiming and shooting, and to determine the mental status and active brain regions in different shooting stages. Differences in the EEG characteristics between the experts and novices were analyzed for different stages. Training simulation interfaces can be designed according to the EEG characteristics of different personnel, for the development of mental training programs, for training the neural state of novices, and also for monitoring the EEG signals of personnel. A closed-loop human-computer interaction was used as the foundation to realize the two-way transmission of information.

2. Materials and Methods

2.1. Participants. Seventeen healthy male experts with rifle shooting experience and fifteen healthy male novices with no shooting experience were recruited; their mean (± SD) age was 25.83 (± 2.46) years. All participants were right-handed and had no major brain disease and their mental states were well. The visual acuity or corrected visual acuity of the participants was 4.8 or higher. The participants were to ensure that they had adequate sleep two days before the experiment and they were forbidden from ingesting stimulating drinks, such as strong tea or coffee.

2.2. Procedures. The participants conducted five shooting exercises to warm up with semi-automatic sniper rifles before the formal experiment. After warming up, the participants were required to complete six rounds of shooting, including 10 trials with intervals of one minute between each round of shooting. The experimental process is shown in Figure 1. Each participant understood the process of the experiment, took the experiment seriously, and maintained a consistent mental state. The distance between the chest ring targets and the participants was 70 m. The participants were in a sitting position and their guns were supported by instruments. Each shooting process was divided into three stages: holding stage, aiming stage, and shooting stage. A sound was played to signal the beginning of the gun and aiming stages, and there was 1 second between each shooting stage for the participants to make adjustments. A stopwatch was used to record the aiming time of the shooter, which was used to verify the aiming time recorded by the EEG recording software.

2.3. EEG Recording and Preprocessing. Continuous EEG recordings were obtained using a SynAmps2 amplifier (Compumedics Neuroscan, Charlotte, NC, USA). The EEG acquisition equipment included an EEG amplifier (Brain Products, actiCHamp), 32-channel active electrode EEG acquisition cap, EEG synchronous acquisition system, and an ERP/EEG stimulation system. The ERP/EEG stimulation system was mainly used for the subjects who completed the tasks according to the guidelines, and the screen refresh frequency was 60 Hz. The EEG synchronous acquisition system collected, recorded, and saved the brain signals during the shooting tasks by integrating the signal amplification and acquisition software. The electrodes were placed on the participants according to the international 10–20 system, the reference electrode was set as Fz, the prefrontal lobe was grounded, the sampling rate was 1000 Hz, and the

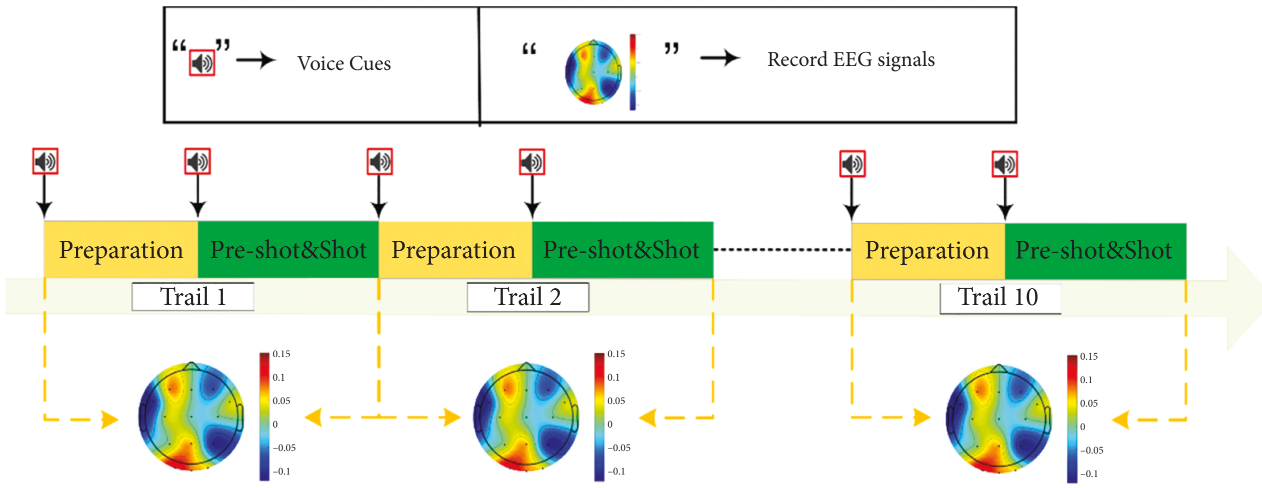


FIGURE 1: Experiment design and procedure.

impedance of the electrode was kept below 5K Ω during the acquisition process.

Independent component analysis (EEGLAB) was used to correct the artifact signal caused by blinking. Using the multi-resolution characteristics of wavelet transform, the EEG signal was decomposed into multiple scales and five independent frequency bands, thus showing different rhythmic information in the frequency band [27, 28]. In order to reduce the time and space complexity of the wavelet packet decomposition, the signal was desampled. The EEG sampling rate decreased from 1000 Hz to 256 Hz.

After the EEG signals from the shooting process were segmented, the data for each participant was grouped into three sets: holding stage data, aiming stage data, and shooting stage data. Each data set was measured over a period of 2 seconds, and the sampling rate was 1000 Hz. During the aiming phase, eye closure had a great influence on the FP1 and FP2 signals in the frontal region; hence the FP1 and FP2 data were not processed in this study, while the temporal area was mainly occupied with hearing and did not do any processing. Finally, out of the 32 channels, we only analyzed the EEG data from 14 channels in the frontal region (F3, Fz, F4), frontal-central region (FC5, FC6, C3, Cz, C4), parietal region (P3, Pz, P4), and occipital region (O1, Oz, O2). Using the multi-resolution analysis characteristics of the wavelet transform, the preprocessed EEG signals were decomposed into five sub-frequency bands using multi-scale decomposition. The relative wavelet packet energy and three wavelet packet energy ratios for the five frequency segments of the EEG data were calculated for each of the three shooting stages. The five frequency bands were delta (δ: 0-4 Hz), theta (θ: 4-8 Hz), alpha (σ: 8–13 Hz), beta (β: 14–30 Hz), and gamma (γ: 31–40 Hz).

Next, the relative wavelet packet energy parameters for all the leads from each subject were calculated for the three shooting stages. Comparative histograms were drawn for the relative wavelet packet energy of the different shooting stages, and separate brain topographic maps were drawn for the aiming state (aiming state = aiming stage wavelet packet energy-holding stage wavelet packet energy) and shooting state (shooting state = shooting stage wavelet packet energy-holding stage wavelet packet energy).

3. Results

3.1. Wavelet Packet Energy of Novices. Figure 2 shows the brain topographic maps of differences in the wavelet packet energy characteristics between the aiming and holding stages in novices. It can be seen that the wavelet packet energy of the β frequency band F3, Pz, O1, O2, Oz, γ frequency F3, Fz, FC6, P3, Pz, Oz, F3, Fz of α/θ, F3, and Oz of frequency parameter β/α increased significantly in the aiming stage as compared with the holding stage. These results indicate that the novices were in a state of high vigilance and the EEG energy of the β frequency was more concentrated [29], which is in line with the previous work.

Figure 3 shows the brain topographic maps of the differences in wavelet packet energy characteristics between the shooting and aiming stages in novices, which can be compared with the holding stage. During the shooting phase, the wavelet packet energy of EEG in F3, Fz, FC6, Cz, Pz, O1, O2, Oz of β band, F3, F4, Fz, FC5, C4, Cz, P3, Pz, Oz leads in γ frequency band, F3, Cz, Pz, O1, O2 leads in frequency parameter α/θ, and the F3, C3, P3, Pz, O1, O2, Oz leads in β/α increased significantly. The results showed that the main areas that changed in novices during shooting were the frontal area, the central area, and the occipital area, indicating that the novices not only performed the shooting action during the shooting stage, but also maintained visual attention, which was due to visually induced motion perception which relied on visual-vestibular interactions [30].

3.2. Wavelet Packet Energy of Experts. Figure 4 shows the brain topographic maps of the differences in wavelet packet energy characteristics between the aiming stage and holding stages. It can be concluded that the wavelet packet energy of the F3, Fz, C3, Cz, O2, Oz leads in β, F3, Fz, C3, Cz, Oz leads in γ, and the C3, P3, O2, Oz leads in β/α were significantly increased in the aiming stage as compared with the holding

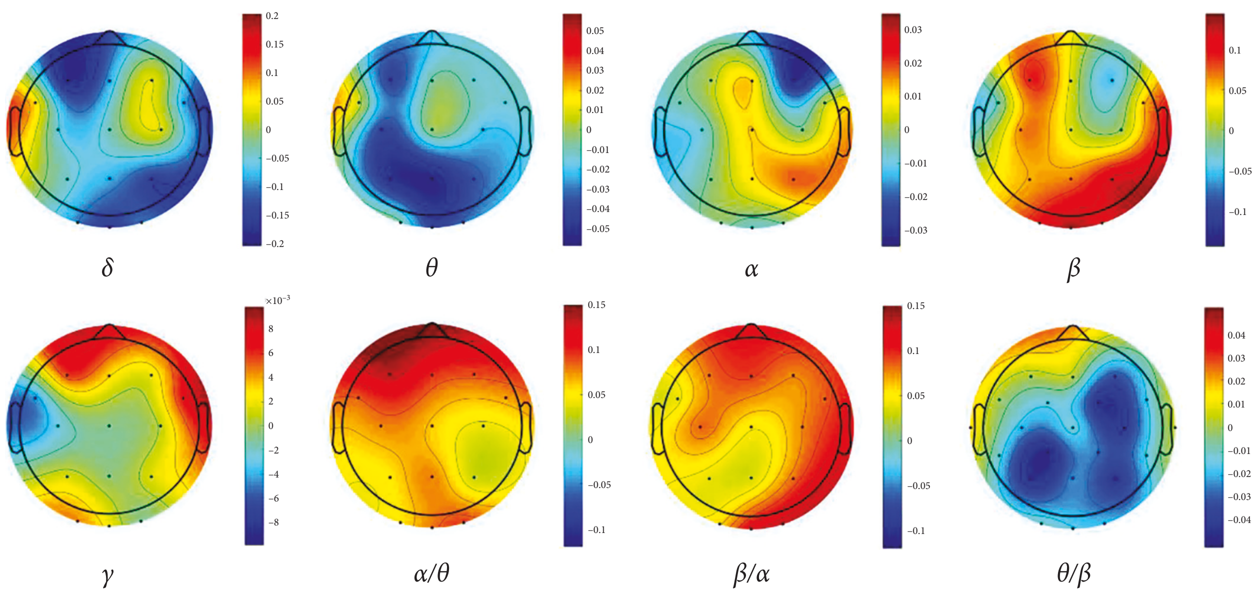


FIGURE 2: Brain topographic map of wavelet packet energy difference between aiming and holding stage in novices.

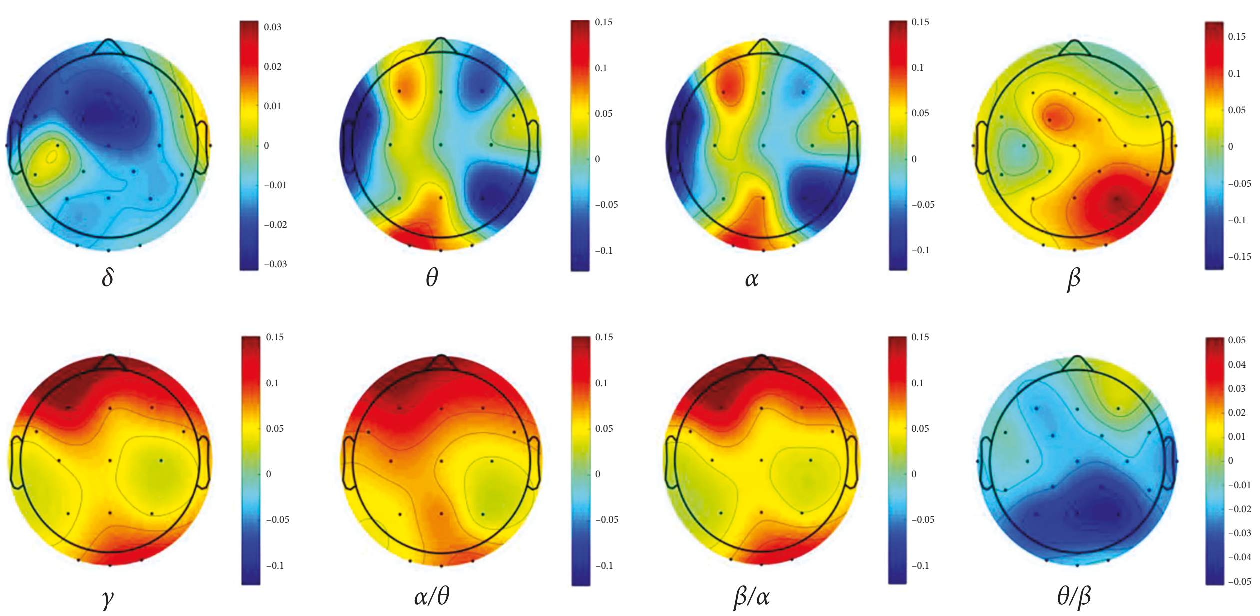


FIGURE 3: Brain topographic map of wavelet packet energy difference between shooting and aiming stage in novices. $^*p < 0.05$

stage. The results show that the frontal, central, and occipital regions were the main areas of change during the aiming state, which is consistent with the conclusion that the central area is related to exercise planning [24].

Figure 5 shows that, in the shooting stage, the wavelet packet energy of almost all the expert leads in $\beta, \gamma, \alpha/\theta$, and β/α is higher than that in the holding stage, and significant changes were observed in the frontal, central, parietal, and occipital regions of the experts during the shooting state. These results show that the experts exhibited higher levels of vigilance and attention in the shooting stage than in the aiming stage, which is similar to Haufler's study that showed experts exhibited lower cortical activity during aiming [31]. Compared with Figure 4, the decrease of α rhythms shows that the non-task-related cognitive processes were suppressed shortly before shooting [7], and the gradual decrease of γ rhythm means that the brain is activated, which indicates that γ rhythm is related to attention, arousal, and object recognition [32]. This might be explained by the experts' long-term training which caused specific changes in areas of the experts' brains that were associated with the shooting exercise, i.e., a neuroplasticity effect [9].

3.3. Difference between Novices and Experts. Figure 6 and Figure 7 show the difference of wavelet packet energy characteristics between novices and experts in aiming and shooting stages. Values of F3, C3, P3, O1, Fz, Cz, Pz, O2 in β

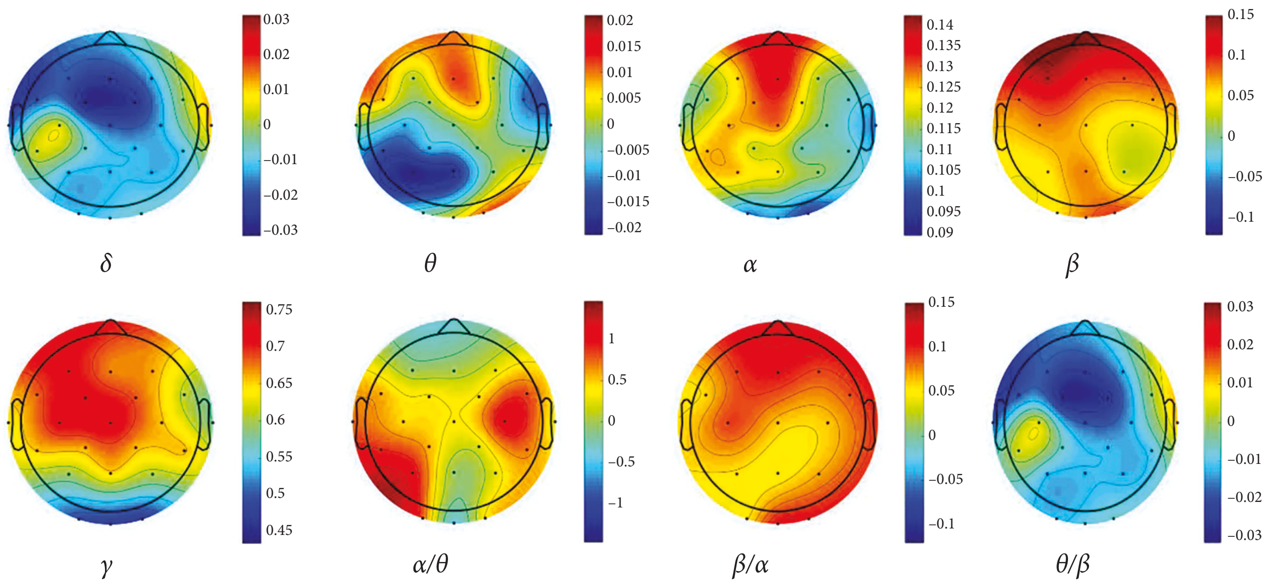


Figure 4: Brain topographic map of wavelet packet energy difference between aiming and holding stage in experts.

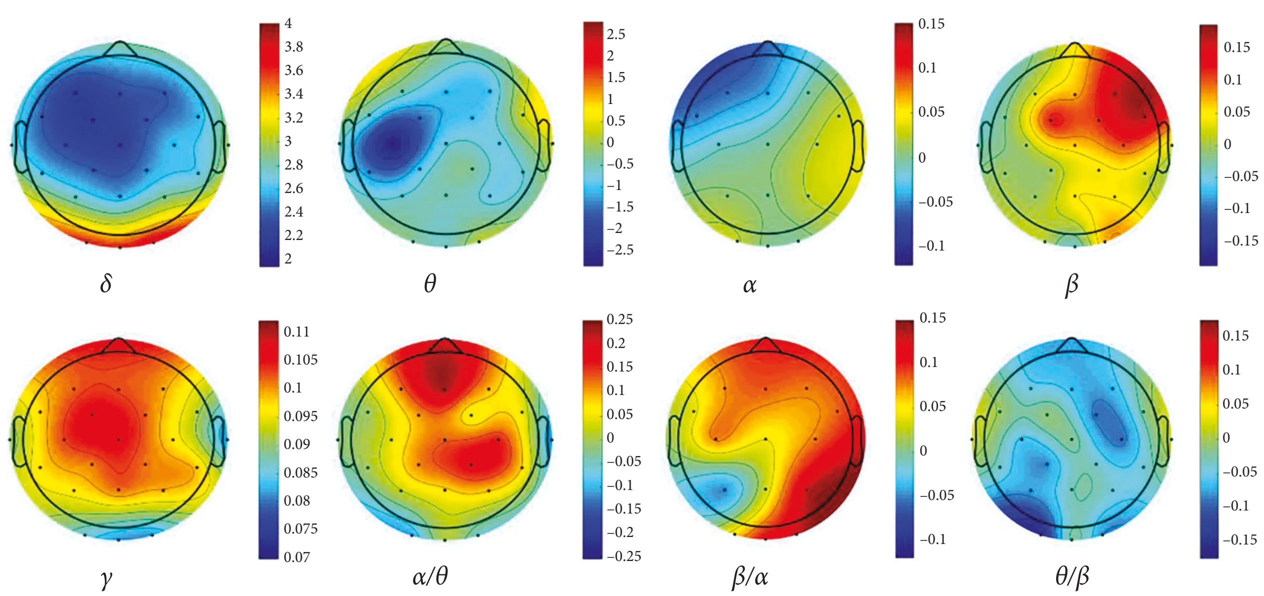


Figure 5: Brain topographic map of wavelet packet energy difference between shooting and aiming stage in experts.

band had group main effect, values of FC5, C3, P3, Pz, Oz, F4, C4, P4, O2 in γ band had group main effect, ratios of FC5, C3, P3, Pz, Oz, F4, C4, P4, O2 in α/θ band had group main effect, and ratios of F3, FC5, C3, P3, Cz, Oz, F4, FC6, C4 in β/α had group main effect.

In the aiming stage, the P4 and Pz of novices in the β and γ bands, and the C3 and C4 of the γ band, were significantly higher than those of the experts, indicating that for the novices the parietal region was precisely the location of the functional brain region during aiming [33].

For the experts, their functional brain region was the central region, which corresponds to the area of action. These results reflect that experts had already planned the shooting action in the aiming stage, and the parietal region was responsive to the main activity area [13], indicating that novices were more attentive during the aiming state. This shows that there was a difference in the brain characteristics of novices and experts during the aiming state.

In Figure 7, the energy levels of the experts in the F4, FC5, P3 leads of the β band, FC5, C3 leads of the γ band, F4 leads of α/θ and F3, Fz, FC5, Cz, P3 leads of β/α were significantly higher during the shooting stage than those of the novices. In other words, the bands on multiple thresholds of shooting for the experts were significantly different from those of the novices, which indicates that the frontal and central regions of the left hemisphere of the brain remained active for experts for a period of time during the shooting stage, which may be the maintenance of the shooting state.

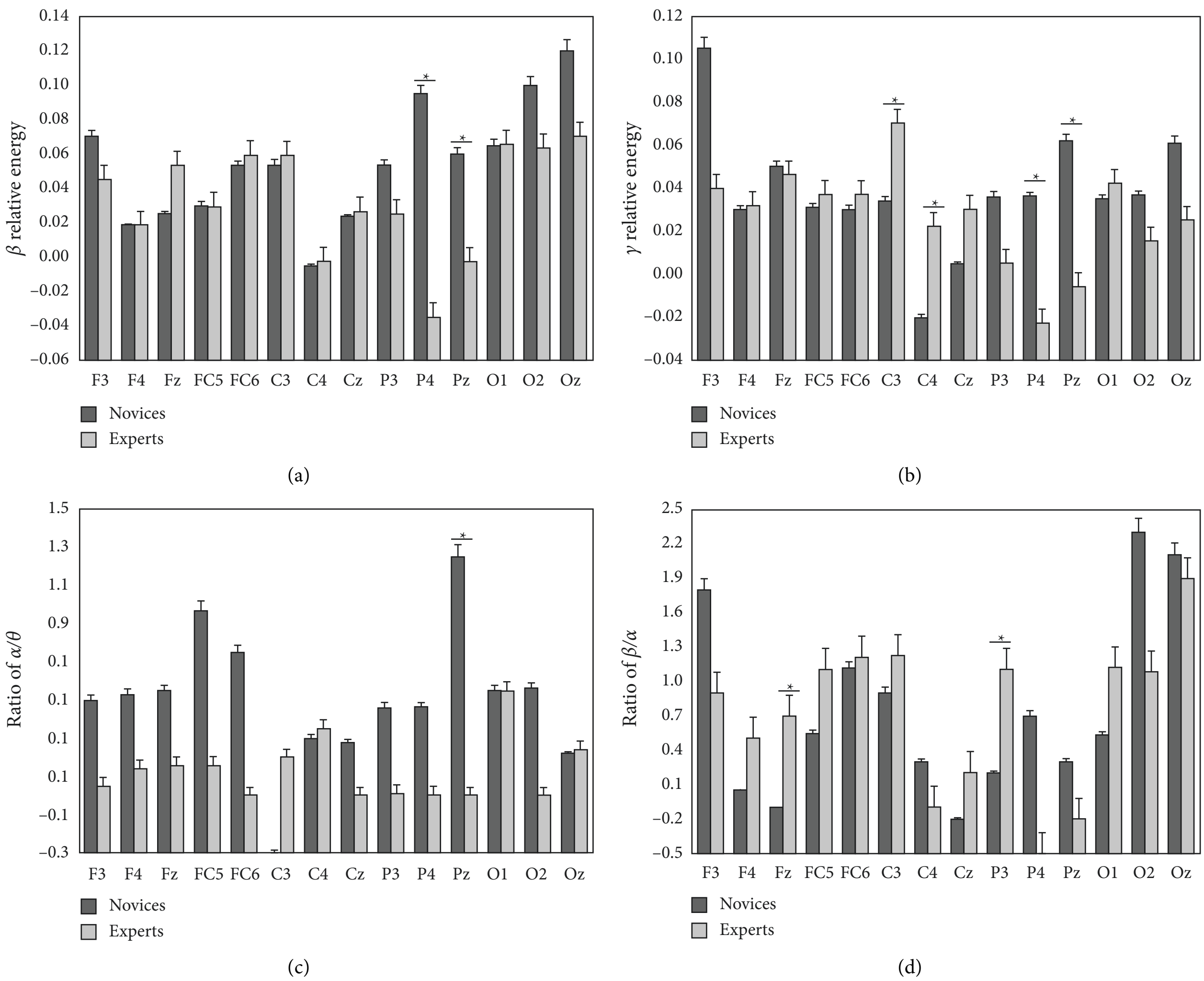


Figure 6: Significant differences of wavelet packet energy between novices and experts in aiming phase. $^{*}p < 0.05$.

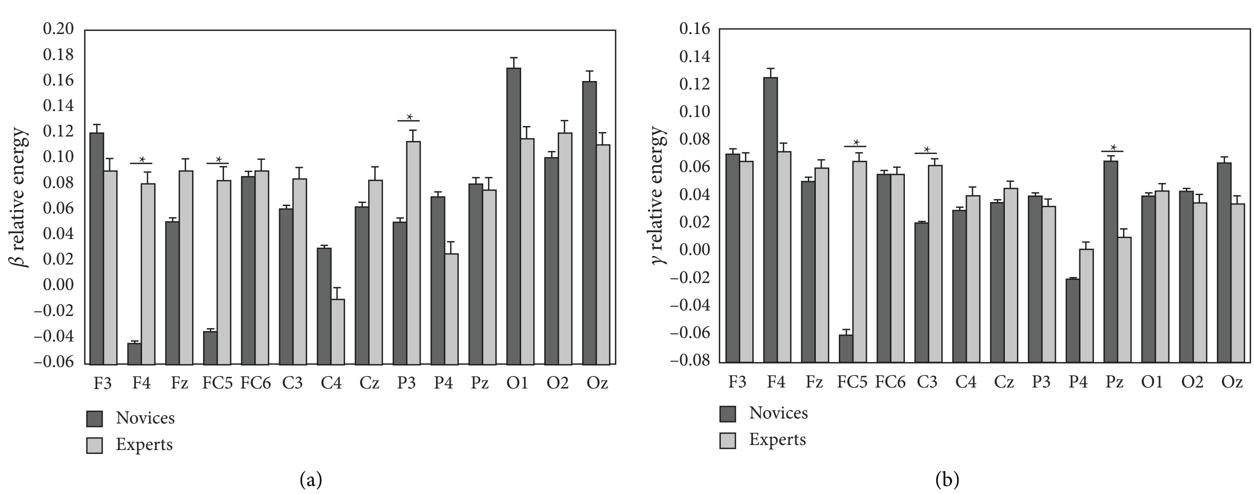
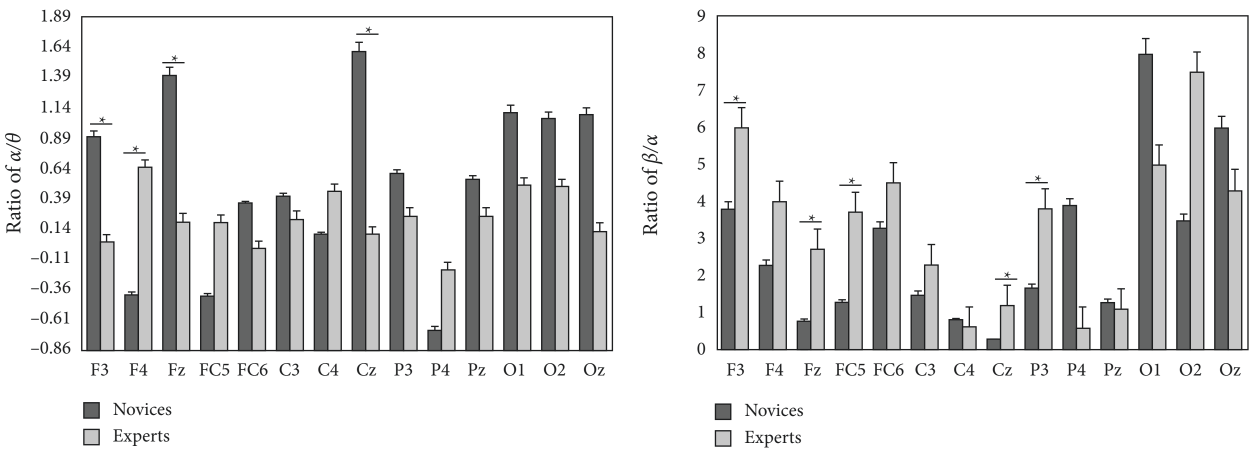


Figure 7: Continued.



(c) (d)

Figure 7: Comparison of wavelet packet energy difference between novices and experts in shooting phase. $^{*}p < 0.05$.

4. Discussion

In this study, an offline wavelet packet energy analysis was conducted using multi-lead EEG data to quantify the energy characteristics of each frequency band for different lead EEG signals in different shooting stages. The differences in wavelet packet energy characteristics of the experts' and novice' EEG signals were analyzed at different frequency bands.

Results showed that, in the aiming state, the frontal and occipital regions changed the most for novices, while the frontal, central, and occipital regions changed the most for experts. The frontal, central, and occipital regions are related to attention and vision, indicating that visual attention was more highly activated in the aiming stage. Furthermore, the main changes in the brain areas occurred in the frontal and occipital regions, which are biased to the left side of the brain [34]. In the shooting stage, the main changes in the novices occurred in the frontal, central, and occipital areas, while the main change in the experts was in the frontal, central, parietal, and occipital areas. This shows that for the shooting stage, regardless of whether the participant is an expert or a novice, progress can be achieved by developing adaptive strategies, suppressing task-independent stimuli, processing environmental stimuli, and refining internally generated clues, making the shotter maintain visual attention. In particular, compared with the gun stage, the experts paid more attention to shooting efficiency if they had paid more attention during the aiming stage, and the EEG power of the parietal and occipital regions of the experts was higher [22].

By comparing the characteristics of the wavelet packet energy of the novices and experts, it was found that the wavelet packet energy of experts was significantly lower than that of novices in the β and γ frequency bands of the aiming state. The γ band was regulated by sensory input, which was related to working memory, learning, and attention [35], which shows that the novice's parietal region needs more resources to integrate different types of sensory information to produce spatial awareness and improve the accuracy of their aim. From the characteristics of the wavelet packet of the aiming state, it was seen that the experts' neural efficiency (a lower consumption of energy represents more effective tissue cortical functions) was higher, indicating that the experts' attention strategy and visual search mode were more efficient [24].

It should be noted that the changes of the θ frequency band of the novices during the aiming and shooting stages were equivalent to those changes that occurred in the experts. In addition, the largest θ change in the experts occurred in the aiming stage, indicating that the lower θ activity in the novices may be the result of a lower degree of automation in their shooting process [31]. Comparing results with the novices in the study by Doppelmayr et al., the conclusion of the θ activity of the frontal region of the experts in both studies was consistent to within about half a second before shooting [7]. θ was obviously distributed in the forehead and central region, which can be used as a neural marker to distinguish the performance state between experts and novices [1].

The above conclusions provide support for the neural or processing efficiency theory. That is, not only were the brain regions of novices and experts activated in relation to the task, but they also inhibited the brain regions that were not related to the task, and different regions were activated during different shooting tasks. Therefore, we can select, train, and supervise personnel at different levels of proficiency and performance according to EEG signals.

A limitation of this study is that we did not take into account the differences in EEG signals between the experts and novices when paying attention to related tasks. By comparing the EEG characteristics that affect the shooting performance of experts and novices, the training stimulation interface can be designed according to their characteristics, such as making special marks on the identified objects, increasing the recognition direction, and so on, which would not only conserve equipment resources, but also improve the progression from novice to expert.

5. Conclusion

Combined with the EEG characteristics of shooter's aiming state and the mechanism of visual spatial selective attention, we studied the changes of EEG signals of shooters in the process of holding gun, aiming, and shooting in real shooting environment. Based on the frequency domain characteristics of EEG signals, the wavelet packet energy analysis method is used to analyze the EEG characteristics of professional shooting and novice shooting. Based on the EEG signals in the holding phase, the differences of brain regions and EEG characteristics of brain activity between experts and novices in the aiming and shooting stages were explored, and the brain regions and locations of the leads were determined. One of the innovations of this study is that we extract and classify the EEG characteristics of operators with different proficiency levels when performing typical tasks that require attention.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

Shuyu Shao contributed to original draft preparation. Shike Zhang contributed to editing and supervision. Liwei Zhang contributed to reviewing the manuscript.

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