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Neurofeedback Training for Rifle Shooters to Improve Cognitive Ability

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***Abstract*—Neurofeedback training is one type of the biofeedback training that allows the subject do self-regulation during the training according to his/her real-time brain activities recognized from Electroencephalogram (EEG) and given to him/her through visual, audio or haptic feedback. The Neurofeedback training has proven to be helpful in improvement of cognitive abilities not only for patients with mental illnesses but also for healthy subjects including athletes. In this paper, we proposed an experiment in which we recruited elite shooters and conducted a novel individual beta-1/theta based neurofeedback training to confirm the usage of neurofeedback training in boosting the performance of rifle shooters. The efficiency of the neurofeedback training was examined by comparing the shooting scores and results of DAUF test assessing the ability of sustained attention of the shooters before and after neurofeedback training.**

Keywords-neurofeedback; performance of athletes; individual frequency range; EEG; rifle shooters

I. INTRODUCTION

Nowadays, athletes are facing more and more challenges and a higher competition. To look for ways how to enhance performance following the rules in sport, various research is done. Sports nutrition is one of the research focuses to improve athletes' performance. For example, the dietary intakes and food consumed were studied in [1]; hydration strategies were emphasized in [2]. Besides that, a lot of work has been done on the strategy for physical preparation. For example, the training intensity was investigated in [3]; the influence of different high-intensity interval training was studied in [4]; the effect of core stability and strength was discussed in [5]. In addition to the physical preparation, mental preparation plays a decisive role in optimizing the performance. Traditional sports psychological training includes meditation [6], goal setting, positive thinking and self-talk, concentration and routines, arousal regulation techniques, and imagery [7], etc. Novel training such as biosignal based training is being introduced recently. In this paper, we study the Electroencephalogram (EEG)-based neurofeedback training (NFT) to improve shooters performance. Compared with other strategies, EEG signals can reflect the inner and true feelings of the user, and NFT allows them to do self-regulation without the participation of psychologists. To validate the proposed NFT protocol, a preliminary experiment was conducted with 5 shooters. All of them participated in up to 7 NFT sessions. The efficiency of NFT is tested by the shooting performance and results of DAUF test to assess cognitive abilities such as sustained attention of the shooters before and after training. The results show that the majority of the shooters gained improvement in the scores after NFT training sessions.

The paper is organized as follows. Section II reviews the EEG rhythms and NFT protocols for performance optimization. Section III introduces the proposed experiment design and neurofeedback protocol. Section IV presents the results and Section V concludes the paper.

II. RELATED WORK

A. EEG rhythms

EEG rhythms can be categorized to five bands according to the frequency ranges. From 0.5 - 4 Hz is defined as delta wave. It is associated with deep sleep however can still be present while the subject awake [8]. Theta band ranges from 4 - 8 Hz, which is related to drowsy state. Recent research also finds that training-down theta power can help to improve the verbal IQ, executive functions and attention for seniors [9] and be used as the training protocol to deal with mental disorder such as ADHD [10, 11]. The alpha wave, which ranges from 8 to 12 Hz, is associated with relaxation, meditation and a lack of concentration and attention to any specific tasks or objects. Beta wave, of which the frequency range is from 12 to 30 Hz, is always apparent when a subject is actively thinking about something or focusing on an object or task [8]. Unlike theta wave, beta power is always training-up in ADHD treatment [10, 11] and it also shows that training up beta power can help to reduce the reaction time in the attention test for healthy subjects [12]. The last group of brain wave, 30Hz and above, is called gamma wave. This wave is much more rarely observed and tends to indicate the presence of a brain disease.

B. Neurofeedback training for performance optimization

In recent years, researchers have started to focus on performance optimization of shooters using neurofeedback training [13, 14]. In [13], it investigated the effect of neurofeedback training (NFT) on expert rifle shooters and two NFT protocols were used in this study. One involved increasing the sensorimotor rhythm (SMR, 13-15 Hz) while inhibiting high-beta (20-30 Hz) whereas the other involved training crossover between alpha (8-12 Hz) and theta (4-8

Hz) with high-beta suppression. The results revealed that the marksmen who underwent training showed significant improvements in performance after fifteen sessions of training comparing with control group [13]. Another commonly used protocol for NFT to achieve positive effects on performance in sports is the ratio of beta to theta power [15]. [15] has researched on the use of beta/theta ratio to study physical balance and posture improvement and claimed that regulating corresponding brain activity has improved the physical balance in individuals with balance problems.

Besides the use of standard frequency range of EEG, there are works study individual frequency based NFT. For example, [16] showed that individual frequency range based NFT is more efficient compared with standard range. In our previous work, we compared the EEG-based Neurofeedback using individual upper alpha power and individual beta-1/theta ratio [17]. The results showed that using ratio-based training is less affected by artifacts. We also further proof the usage of ratio-based training in enhancing the individual alpha peak and alpha bandwidth in [18]. Thus, in this paper, we employed the individual beta-1/theta based NFT, which is further explained in Section III.

C. *Vienna Test – DAUF for sustained attention*

The Vienna Test System provides a series of psychological tests which can be used to measure the cognitive ability of the testee [19]. In this work, we use the DAUF test to assess the ability of sustained attention of the shooters. There are three test forms. As Form 1 and 2 are mainly for clinical usage, we apply Form 3 which is for normal usage in our study. In Form 3, 7 triangles are shown in one row and the testee needs to react when three of them point downwards. Additionally, the changes in row position are irregular. The main variables of DAUF include sum correct which indicate the total number of correct reaction to the desired stimuli, mean time correct which shows the mean reaction time for correct response, sum incorrect which gives the total number of incorrect reaction, and mean time incorrect which shows the mean reaction time for incorrect response.

III. Methods

In order to assess how neurofeedback can improve performance in shooters we carried out an experiment where neurofeedback training is given to the athletes.

A. *Experiment design*

5 elite female shooters participated in the experiment. 4 participants underwent 7 sessions of NFT and 1 participant underwent 6 sessions. Before and after NFT the 10m air rifle shooting sessions were conducted and were used as an index of shooting performance. The EEG data was recorded during the shooting sessions and NFT session. Emotiv device [20] with 14 channels was used in the experiment to collect EEG data. All subjects needed to fulfil an intake questionnaire at the first time when they came to the shooting range.

B. *Neurofeedback Protocol*

The neurofeedback training protocol is to enhance beta-1/theta ratio (suppression of theta/beta-1 ratio).

To decide the frequency range of beta-1 and theta which is used in the neurofeedback training, the individual alpha peak frequency and bandwidth is calculated. As the individual alpha band is suppressed in eyes-open EEG data and dominant in eyes-closed EEG data, we recorded one-minute eyes-open and one-minute eyes-closed EEG data to obtain the individual alpha band. According to [16, 21], alpha peak frequency is the maximum frequency of the power spectral density in the eye-closed EEG curve and alpha bandwidth is the intersected range of the power spectral density in eyes-open and eyes-closed EEG curves. With the individual alpha band obtained, we can define the individual theta band from 3 Hz to the lower alpha boundary, and the beta-1 band from the upper alpha boundary to 18 Hz.

Among all 14 channels of Emotiv device, P8 from parietal lobe was chosen to be used in the neurofeedback according to our previous work [18]. A shooting game was used in the NFT session. The shooting game is chosen, as it is closer to the rifle shooter's expertise. When the beta-1/theta ratio value is larger than threshold, the subject is able to shoot the robots in the game. The subjects need to adjust the brain state from undesired to desired one based on the feedback from the NFT game and learn to maintain that state as long as possible during the game.

C. *Neurofeedback Procedure*

The procedure of the neurofeedback training is as shown in Table I. In this table, EO denotes eyes-open state and EC denotes eyes-closed state. The questionnaire before NFT is about the feeling on that day before the NFT such as is there any headache, any medicine taken before the neurofeedback training, etc. The questionnaire after NFT is about sleep diary and feelings after NFT such as tiredness, the strategies used during the game to achieve the desired brain state.

TABLE I. PROCEDURE OF NFT SESSION

Steps		Condition	Duration	Electrophysiological records
1	Fill a Questionnaire	EO	5 min	-
2	Rest	EC	1 min	Raw EEG (μV, 128Hz)
		EO	1 min	
3	NFT	EO	10 min	Raw EEG (μV, 128Hz)
4	Rest	EC	1 min	Raw EEG (μV, 128Hz)
		EO	1 min	
5	Fill Questionnaires	EO	10 min	-

During NFT, the subjects are first asked to try the strategy they are familiar with in the shooting experience. Other instructions such as fingers heating [22], abdominal breathing [23], expiration prolongation [24], position stability [25], forehead muscle relaxation [26], nice imagination [27] are given for the subjects to try to change the color of the robots from blue to red.

IV. RESULTS

A. Before and after-NFT performance in shooting

To validate the impact of the NFT on the shooters, we compare the total score of two shooting sessions which was carried out before and after NFT respectively as shown in Table II. Here S1 denotes the shooting session before NFT, and S2 is the shooting session after NFT. Each session is comprised of 40 shots and the total score is tabulated in Table II. From the table we can conclude that the neurofeedback training helps in the shooting performance as Subject 2, 4, and 5 have improvement of the shooting scores. Subject 1 and 3 seemingly have slightly worse score after NFT. So we further examined the distribution of the shooting scores before and after NFT. The 25th, 50th, and 75th percentiles in terms of the shooting score are presented in Table III. From the distribution it can be seen that there is no any significantly drop of the score for Subject 1 and 3. However, we can see Subject 2, 4, and 5 have both the total score and distribution improved.

Another interesting phenomenon we observed from Table II was that subject 5 gained the most significant improvement of the total shooting score when before and after NFT results were compared. Considering the shooting score before NFT of Subject 5 was the lowest one, it could be concluded that NFT was more efficient in helping subjects whose ability was relatively lower.

Additionally, the coaches of the participated shooters gave thresholds of each shooter using which, we were able to identify how many good shots were in the before and after NFT training. The comparison is given in Table IV. Again, except subject 1 and 3, all the other subjects got improved or equal shooting performance after NFT.

TABLE II. TOTAL SCORE FOR BEFORE AND AFTER NFT

Subject ID	Session ID	
	S1	***S2***
	total score	***total score***
1	415.3	414.9
2	414.4	417.3
3	412.7	409.2
4	411.7	412.3
5	410.9	416.4

TABLE III. PERCENTILE OF THE SHOOTING SCORE

Subject ID	Session ID	Percentile		
		25%	***50%***	***75%***
1	S 1	10.2	10.4	10.6
	S 2	10.2	10.4	10.6
2	S 1	10.1	10.4	10.6
	S 2	10.2	10.5	10.6
3	S 1	10.1	10.4	10.5
	S 2	10	10.2	10.6
4	S 1	10.1	10.3	10.5
	S 2	10.1	10.4	10.6
5	S 1	10	10.3	10.5
	S 2	10.2	10.4	10.6

TABLE IV. NUJMBER OF GOOD SHOTS BEFORE AND AFTER NFT

Subject ID	Session ID	
	S1	***S2***
1	22	21
2	23	25
3	21	13
4	15	15
5	26	32

B. Before and after-NFT performance in DAUF test

The results of before and after NFT DAUF test are presented in Table V. From this table we can conclude that the performance in DAUF is consistent with the total shooting score in Table II, where Subject 1 and 3 did not achieve an improvement after NFT. However, from the result we can see that for Subject 3, there is no difference between sum correct in before and after-NFT DAUF test, and the sum incorrect even decreased in after-NFT DAUF test. Besides other 3 subjects all got the improved performance in DAUF test, either by increased sum correct or decreased sum incorrect, which confirms the efficiency of NFT.

TABLE V. DAUF TEST RESULTS BEFORE AND AFTER NFT

Subject ID	DAUF test results	Session ID	
		S1	***S2***
1	sum correct	279	252
	mean time correct	0.701	0.829
	sum incorrect	4	4
	mean time incorrect	0.682	0.898
2	sum correct	264	271
	mean time correct	0.749	0.756
	sum incorrect	6	9
	mean time incorrect	1.002	0.718
3	sum correct	278	278
	mean time correct	0.6	0.615
	sum incorrect	4	3
	mean time incorrect	0.61	0.636
4	sum correct	273	275
	mean time correct	0.556	0.572
	sum incorrect	5	4
	mean time incorrect	0.438	0.578
5	sum correct	279	279
	mean time correct	0.784	0.765
	sum incorrect	4	2
	mean time incorrect	0.846	0.738

C. Correlation analysis

In this section, we further studied the correlation between the change in shooting performance and in DAUF test. We subtracted the before NFT shooting score/DAUF results from the after NFT shooting score/DAUF results and then calculated the correlation coefficients using the change of NFT shooting score and DAUF results. We expected a positive correlation between the change of shooting scores and of DAUF test results.

Due to the limited number of subjects, we could not get significant correlation. However, the trend of correlation is compatible with our hypothesis as presented in Table VI. The change of total shooting score is positively correlated with sum correct, and negatively correlated with mean time correct, sum incorrect, and mean time incorrect, which indicates that the improvement of shooting score between before and after-NFT session was accompanied with the increase of sum of correct reaction in DAUF test, decrease of mean reaction time for correct reaction, sum of incorrect reaction, and mean reaction time for incorrect reaction.

TABLE VI. CORRELATION STUDY

Correlation coefficients	Sum correct	Mean time correct	Sum incorrect	Mean time incorrect
Total score	0.41	-0.7	-0.205	-0.6

V. CONCLUSTION

In this paper, we proposed a novel NFT protocol based on individual beta-1/theta ratio to improve cognitive abilities of rifle shooters. We designed and conducted an experiment with five elite rifle shooters who participated in up to 7 NFT sessions and studied the effect of the proposed NFT protocol on their shooting score results and sustained attention cognitive test results. We showed that the NFT could help the shooters to boost their performance. We also showed that a positive correlation exists between the change of shooting scores and of DAUF test results. In the next step, we expect to recruit more shooters in the study.

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