Neurofeedback Training for Enhancement of the Focused Attention Related to Athletic Performance in Elite Rifle Shooters

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Abstract. NeuroFeedback Training (NFT) is a type of biofeedback training using Electroencephalogram (EEG) that allows the subjects to do self-regulation during the training according to their real-time brain activities. The purpose of this study is to optimize focused attention in expert rifle shooters with the use of NFT tools and to enhance shooting performance. We designed and implemented an experiment, conducted NFT sessions, and confirmed that NFT can boost performance of the shooters. The efficiency of the NFT was examined by comparing the shooters' performance, their results of standardized tests of general cognitive abilities on the Vienna Test System (VTS), and the brain patterns in before and after NFT sessions. According to the results, we confirmed that NFT can be used to boost the shooters' performance. EEG data were recorded during the shooting tasks. We extracted different types of EEG-based indexes and identified the emotion and mental workload levels of the shooters right before they pulled the trigger. These indexes and emotion/workload levels were then correlated with the shooting scores to understand what are the optimal brain states for "good" shots. According to the results, we confirmed that 1) mental workload level is negatively correlated with the shooting performance; 2) the correlations analyses results between EEG-based power features and shooting performance are consistent with the literature review results; 3) the difference of brain states in the before and after NFT shooting session could be because of NFT.

Keywords: Neurofeedback, Performance of Athletes, Individual Frequency Range, EEG, Rifle Shooters, Mental Workload, Emotions

1 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.

In our previous work [8], a preliminary experiment with 5 elite shooters participating in up to 7 NFT sessions was described. The efficiency of NFT was analyzed by the shooting performance and results of DAUF test from Vienna Test System (VTS) to assess cognitive abilities such as sustained attention of the shooters before and after training. The results showed that the majority of the shooters gained improvement in the scores after up to 7 NFT sessions. In this paper, we extended the work described in [8] with analyses of physiological indexes calculated from EEG. Standardized alpha, beta, theta/beta ratio, SMR, beta1, and beta2 were extracted from EEG and analyzed to study correlation between the EEG-based indexes and the shooters' performance results before and after NFT. The definitions of the EEG rhythms are given in Section 2.1. Brain states such as emotions and workload levels were identified and the correlations with the shooters' performance results before and after NFT were analyzed. Based on the results, it is revealed that the NFT changed the correlations, in other words, the brain states could be adjusted by NFT.

To recognize emotions and workload levels, the algorithms proposed in our previous work [9] and [10] were applied. Fractal dimension and statistical features were extracted from the raw EEG data and used to train the Support Vector Machine (SVM) classifier. The saved SVM model then was used to identify the brain states during shooting before and after NFT.

The paper is organized as follows. Section 2 reviews the EEG rhythms, NFT protocols for performance optimization, and Vienna test. Section 3 introduces the proposed experiment design and NFT settings. Section 4 presents effect of NFT and Section 5 concludes the paper.

2 Related Work

2.1 EEG Rhythms

EEG rhythms can be categorized to five bands according to the frequency ranges. The rhythm from 0.5 - 4 Hz is defined as delta wave. It is associated with deep sleep however can still be presented while the subject is awake [11]. 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 [12] and be used as the training protocol to deal with mental disorder such as Attention Deficit Hyperactivity Disorder (ADHD) [13, 14]. 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 [11]. Unlike theta wave, beta power is always trained-up in ADHD treatment [13, 14] and it also shows that training up the beta power can help to reduce the reaction time in the attention test for healthy subjects [15]. The last group of brain wave, 30 Hz and above, is called gamma wave. This wave is much more rarely observed and tends to indicate the presence of a brain disease.

2.2 NeuroFeedback Training for Performance Optimization

In recent years, researchers have started to focus on performance optimization of shooters using NFT [16, 17]. In [16], the effect of NFT was investigated 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 NFT showed significant improvements in performance after fifteen sessions of NFT comparing with control group [16]. Besides rifle shooters, study about the impact of NFT on air-pistol shooters was done in [18-22]. In [18], Event Related Desynchronization/ Synchronization (ERD/ERS) in lower alpha (8-10 Hz), higher alpha (10-12 Hz), beta (16-24 Hz) and theta (4-8 Hz) frequency band was analyzed to identify the neural markers associated with optimal and sub-optimal performance in air-pistol shooters. The results of the study concluded that optimal and sub-optimal performance was associated with a different cortical pattern and ideal performance occurred with an increase in the lower alpha band which was associated with relaxation states. Based on this finding, it was suggested that a NFT protocol could be increasing lower alpha as it led to improvement in the performance. In [19], the effect of cortico-cortical communication on disabled and non-disabled elite air-pistol shooters was investigated. The results revealed that disabled shooters with spinal cord injury had higher coherence in all brain regions of higher alpha (11-13 Hz), and only frontal and central regions of beta (14–35 Hz), and gamma (36–44 Hz) frequency bands compared with non-disabled shooters. These results were used to reduce activation in task-irrelevant cortical areas and hence suggested that application of appropriate NFT can improve the performance of disabled shooters. Work [20] used the NFT protocol of increasing left temporal alpha power and the results showed that after NFT, both left temporal alpha power and shooting scores were improved. In [21], it showed that by increasing beta 1 and SMR amplitude in pistol shooters, they were able to reduce irrelevant muscles activities during shooting, which in result, led to better psychomotor function and cognitive control. Following the protocol in [21], [22] showed that by

enhancing beta 1 and SMR amplitude while inhabiting theta band, the autotelic engagement of attention of athletes was improved.

In other areas of sports, NFT is also used to optimize the performance of athletes. For example, studies have been carried out with individuals in the fields of archery and golf [23-25]. The training protocol involved the self-regulation of SMR frequency which corresponds to deceleration of heart rate and improvement in archery performance [23]. In [24], a research was conducted with a group of golfers. The correlation between sensorimotor alpha and beta rhythm with upright balance and arm movement control were investigated. As successful golf putts were characterized by high frequency alpha, [24] concluded that a NFT protocol to increase the alpha band frequency in golfers will enhance their performance. The effect of NFT for golfers was studied in [25]. The golfers were trained to reduce their frontal high-alpha power before striking. The results showed that golfers were able to give robust performance even under high pressure conditions which can be accredited to the NFT.

Another commonly used protocol for NFT to achieve positive effects on performance in sports, posture rehabilitation, and treatment of Attention Deficit Hyperactivity Disorder (ADHD) is to train the ratio of beta to theta power [26-29]. [26] has researched on the use of beta/theta ratio to study physical balance and posture improvement. It is claimed that regulating corresponding brain activity has improved the physical balance in individuals with balance problems. The meta-analysis investigating the theta/beta ratio in ADHD groups showed that the healthier control groups have lesser theta/beta ratio whereas the ADHD groups showed higher ratio values in [27]. The experiment also warranted the use of theta/beta ratio as both a prognostic measure and a reliable diagnostic measure of ADHD. An experiment to measure the attention level of individuals by using machine learning approach on the EEG data has shown that self-regulation of theta/beta ratio was important to overcome ADHD symptoms and improve attention levels [28]. In [29], the effect of NFT on attention deficit children was studied and the training protocol aimed at suppression of theta band (4-8 Hz) and improvement of beta band (13-20 Hz). The results showed that children who had attended NFT gained behavioral improvements.

Besides the use of standard frequency range of EEG, there are works studying individual frequency based NFT. For example, [30] showed that individual frequency range based NFT was more efficient compared to standard range. In our previous work [31], we compared the EEG-based NFT using individual upper alpha power and individual beta/theta ratio. The results showed that using ratio-based training was less affected by artifacts. We also further proofed the usage of ratio-based training in enhancing the individual alpha peak and alpha bandwidth in [32]. Thus in this paper, we employed the individual beta/theta based NFT, which is further explained in Section 3.

2.3 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 testees [33]. For example, it can measure spatial visualization, focused attention, concentration, etc, and be used to assess the suitabil-

ity for certain jobs, in our research, namely the potential for elite shooters. 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 as illustrated in Fig. 1. 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.

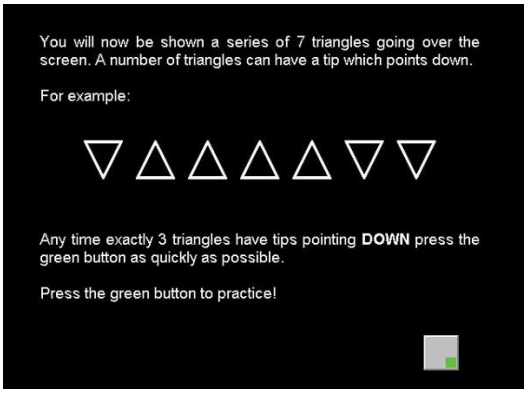

Fig. 1. DAUF test from VTS [33].

3 Methods

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

3.1 Experiment design

The experiment design is shown in Table 1. 5 female shooters were involved in the experiment. All shooters are from Singapore national team. Though due to recruiting time limit, only 5 elite shooters managed to attend the experiment, it is a start to investigate the effect of NFT on shooters. These shooters have undergone up to 7 sessions of EEG-based NFT. Before and after NFT the 10m air rifle shooting sessions were conducted and are used as an index of shooting performance. The EEG data were recorded during the shooting sessions (Fig. 2) and NFT session. Emotiv device [34] with 14 channels were used in the experiment to collect EEG data. All subjects fulfilled an intake questionnaire at the first time when they came to the shooting range.

Table 1. Experiment design.

Phase of Study	Duration	Purpose
Familiarization	1 hour	Lab-based DAUF test
Pre-training	1 hour	Lab-based DAUF test
Pre-training	2 hours	1) EEG-based emotion and workload recognition calibration 2) 1 min open/1 min close eyes recording 3) Dry Fire – 15 shots 4) To record EEG during 40 shots at shooting range as shown in Fig. 2.
NFT	30 min x 6 sessions	1 min open/1 min close eyes recording 10 min lab-based NFT 1 min open/1 min close eyes recording
Post-training	1 hour	Lab-based DAUF test

Fig. 2. Subject wearing EEG device at the shooting range.

3.2 NeuroFeedback Protocol

The shooters went through 6 NFT sessions. The NFT protocol was to enhance beta-1/theta ratio (suppress theta/beta-1 ratio).

To decide the frequency range of beta-1 and theta which is used in the NFT, 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 [30, 35], 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 NFT according to our previous work [32]. A shooting game was used in the NFT session (Fig. 3). When the beta-1/theta ratio value is larger than threshold,

the color of the robots changes from blue to red and the subject is able to destroy the robots. 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. The shooting game was chosen as it is closer to the rifle shooter's expertise.

Fig. 3. NFT shooting game.

3.3 NeuroFeedback Procedure

The procedure of the NFT is given in Table 2. The subject needed to fill a questionnaire which is about the feeling on that day before the NFT such as is there any headache, any medicine taken before the NFT. Then, the 1 min eyes-closed and eyes-opened EEG was recorded. These recordings were used to calculate the individual alpha peak frequency and individual alpha bandwidth to get the range for the individual beta-1 and theta frequency. Then, the theta/beta-1 ratio during open eyes was calculated from the recorded EEG and used for NFT. The subject needed to complete one 10 minutes sub-session that includes NFT game playing. After that, the subject needed to record 1min eye-closed and eyes-open EEG again. Finally, she was asked to fill another two questionnaires which is about sleep diary and feelings after NFT such as tiredness, the strategies used during the game to achieve the desired brain state.

While playing the NFT game, the subjects were first asked to try the strategy they are familiar with in the shooting experience. Other instructions such as fingers heating [36], abdominal breathing [37], Expiration prolongation [38], Position stability [39], Forehead muscle relaxation [40], Nice imagination [41] were given for the subjects to try to change the colour of the robots from blue to red.

4 Results

4.1 Performance in Shooting Before and after-NFT

To validate the impact of the NFT on the shooters, we compared the total score of two shooting sessions which was carried out before and after NFT respectively as shown in Table 3. 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 tabu-

lated in Table 3. From the table we can conclude that the NFT helped in the shooting performance as Subject 2, 4, and 5 had improvement of the shooting scores. Subject 1 and 3 seemingly had 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 4. From the distribution, we don't see a significantly drop of the score for Subject 1 and 3. However, we can see Subject 2, 4, 5 have both total score and distribution improved.

Table 2. Protocol 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	-

Table 3. 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

Another interesting phenomenon we observed from Table 3 is that subject 5 gained the most significant improvement of total shooting score when before and after NFT results are compared. Considering the shooting score before NFT of Subject 5 is the lowest one, this observation may give us a hint that NFT is more efficient in helping subjects whose ability is relatively lower as there is more space to improve.

Additionally, the coaches of the participated shooters gave thresholds of each shooter, using which we are able to identify how many good shots were in the before and after NFT. The comparison is given in Table 5. Again, except subject 1 and 3, all the other subjects got improved shooting performance after NFT.

The paired t-test was applied to the total score and number of good shots of before and after NFT shooting sessions, however, no significant difference was found.

Table 4. 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 5. Number 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

4.2 Performance in DAUF test Before and After-NFT

The results of before and after NFT DAUF test are presented in Table 6. From this table we can conclude that the performance in DAUF is quite compatible with the total shooting score in Table 3, where Subject 1 and 3 did not achieve improvement after NFT. However, from the result we can see that for Subject 3, there was no difference between “sum correct” in before and after-NFT DAUF test, and “sum incorrect” even decreased in after-NFT DAUF test. Besides, other 3 subjects all got improved performance in DAUF test, either by increased sum correct or decreased sum incorrect, which supports the efficiency of NFT. The paired t-test was applied to sum correct, mean time correct, sum incorrect, and mean time incorrect of before and after NFT shooting sessions separately, however, no significant difference was found.

4.3 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 corre-

lation coefficients using the changes of NFT shooting score and DAUF results. We expect a positive correlation between the change of shooting scores and of DAUF test results.

Due to limited number of subjects, we could not get significant correlation. However, the trend of correlation is compatible with our hypothesis as presented in Table 7. 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 is 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 6. 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

Table 7. Correlation Study.

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

4.4 Brain States Before and after-NFT

We also compared correlation between shooting scores and the brain pattern right before the shot release in before and after NFT shooting sessions. Well-established EEG power features such as alpha, beta, theta, and beta/theta ratio were used to analyze the brain pattern. Initially, 2 out of 5 subjects had negatively correlated shooting scores against beta power whereas after NFT all 5 subjects exhibited positive correlation. The change may indicate that the subjects were able to adjust their brain pattern by the NFT. It is consistent with the literature [17] which stated that gymnasts and athletes were able to improve attention and emotional stability after NFT. Apart from the change in beta band in the after NFT shooting sessions, higher alpha is associated with better performance as it indicates more relaxed brain state [42]. This is also in line with our results where NFT has resulted in a positive correlation between alpha band power and shooting performance for 4 out of 5 subjects.

Additionally, the effect of NFT was analyzed by study of the asymmetric brain pattern. Two channels were used to get the difference of brain activity between left and right hemisphere. The results showed that before NFT, the difference of SMR band (12-15Hz) was positively correlated with the shooting score for 1 subject in parietal lobe whereas after NFT all 5 subjects had positive correlation. Similarly, the difference of beta was positively correlated with shooting performance for 2 subjects when parietal lobe channels were used in the before NFT shooting session. However, we could see beta was positively correlated with shooting performance for 4 subjects in the after NFT shooting sessions. Besides, we found that before NFT, 3 out of 5 subjects had positively correlated beta/theta ratio with shooting score. For different EEG bands, 3 out of 5 had positive correlation with theta and 2 out of 5 had positive correlation with both beta and alpha. After NFT, 3 out of 5 subjects had positively correlated ratio values. All 5 subjects had positive correlation with theta and beta, and 4 out of 5 subjects had positive correlation with alpha.

We further extended our study to compare the correlation between brain states such as mental workload and emotion, and shooting performance in before and after NFT sessions using the workload/emotion recognition algorithms introduced in Section 1.

We found out that in the shooting sessions before NFT, only 2 out of 5 subjects had negative correlation between the average workload for 4 second before the trigger of the shot and shooting scores. The negative correlation means that lower mental workload (i.e. lower mental efforts) of the shooter before the shot release is associated with the better shooting score. As a contrast, in the shooting sessions after NFT, the average mental workload for 4 second before the trigger of the shot is negatively correlated with the shooting performance for 4 out of 5 subjects. The difference of mental workload states before shot release in the before and after NFT session could be because of NFT. The change of emotional state after NFT is not as obvious as workload. By analyzing the average emotion, mental workload and power features for all the 40 shots in each session, it could be seen that 2 out of 5 subjects had either more positive or neutral emotion after NFT. Also, 2 subjects had lower mental workload after NFT. Before NFT, 3 out of 5 subjects had neutral emotion and 4 out of 5 subjects had medium or low workload. After the NFT, 4 out of 5 subjects' emotion were

either positive or neutral and 3 out of 5 subjects had lower or moderate level of workload.

5 Conclusion

In this paper, we proposed a novel NFT protocol based on individual beta/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. We showed that the NFT could help the shooters boost the performance as the shooters had improvement in the after NFT shooting session and sustained attention test DAUF. We also showed that a positive correlation exists between the change of shooting scores and of DAUF test results. By attending NFT sessions, the shooters were able to adjust their brain states which can be seen from the correlation changes between EEG band power, workload/emotions and the shooting performance in the before and after NFT sessions.

Limited number of elite shooters was recruited to participate in the project experiments because of their tight schedule. Statistical significance was not obtained in the data analysis but the results are consistent with the literature review. In the next step, we expect to recruit more shooters in the study.

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