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Efficiency and fatigue in marksmanship training

Vadim Grubov
Neuroscience and Cognitive Technology Lab,
Center for Technologies in Robotics and
Mechatronics Components,
Innopolis University,
Innopolis, Russia
vvgrubov@gmail.com

Artem Badarin
Neuroscience and Cognitive Technology Lab,
Center for Technologies in Robotics and
Mechatronics Components,
Innopolis University,
Innopolis, Russia
badarin.a.a@mail.ru

Andrey Savosenkov
Brain-Machine Interface Development Lab,
Institute for Neurosciences,
Lobachevskiy University,
Nijnij Novgorod, Russia
deft_wey@mail.ru

Nikita Grigoriev
Brain-Machine Interface Development Lab,
Institute for Neurosciences,
Lobachevskiy University,
Nijnij Novgorod, Russia
kohopadag@gmail.com

Maxim Lukojanov
Brain-Machine Interface Development Lab,
Institute for Neurosciences,
Lobachevskiy University,
Nijnij Novgorod, Russia
sviter33@gmail.com

Anna Ydoratina
Brain-Machine Interface Development Lab,
Institute for Neurosciences,
Lobachevskiy University,
Nijnij Novgorod, Russia
annaudoratina@yandex.ru

Vladimir Maximenko
Neuroscience and Cognitive Technology Lab,
Center for Technologies in Robotics and
Mechatronics Components,
Innopolis University,
Innopolis, Russia
v.maksimenko@innopolis.ru

Viktor B. Kazantsev
Neuroscience and Cognitive Technology Lab
Center for Technologies in Robotics and
Mechatronics Components,
Innopolis University
Innopolis, Russia
kazantsev@neuro.nnov.ru

Alexander E. Hramov
Neuroscience and Cognitive Technology Lab
Center for Technologies in Robotics and
Mechatronics Components,
Innopolis University
Innopolis, Russia
hramovae@gmail.com

***Abstract*—In the present study we developed experimental paradigm and setup for marksmanship training in untrained subjects. We aimed to demonstrate correlation between subject's fatigue and efficiency during training.**

***Index Terms*—marksmanship training, experimental paradigm, fatigue**

I. Introduction

Since the 1960s [1], [2] the ability has been demonstrated for learned control of brain electrical activity through instantaneous feedback, caused by external stimuli or volitional control. While neurofeedback has some simplistic utility such as alpha training for relaxation, more advanced applications include training in sportsmen and elderly. One of the most promising directions is the search for "optimal" or "peak performance" brain activity in healthy subjects assigned to various cognitive tasks. Number of controlled studies showed that neurofeedback protocol can be beneficial and there is a correlation between the feedback learning and the task's outcome.

Neurofeedback training commonly considers one general type of activity at a time — for example, motor activity

[3]–[6]. The most popular training protocol deals with the amplitude of the Sensory Motor Rhythm (SMR) 12–15 Hz band while inhibiting outer-lying bands in the EEG spectrum [7], [8]. In this situation, it is important to develop a well-expressed kinesthetic sense of movement [9]. It is based on the fact that 12-15 Hz frequency oscillations in sensory-motor and pre-motor cortices exhibit a distinctively high power during periods of quiet wakefulness with reduced muscle tone, and are absent during goal directed motor activity. However, if the task is more specific and complex the search of "optimal" brain activity becomes an important subject for research.

In the present research we studied a task in a form of marksmanship training. Such task combines motor activity with visual perception and decision making, thus the search for "peak performance" brain activity is a nontrivial task. Knowledge on such brain activity can be used to enhance the efficiency of training. On the one hand, desired activity can be achieved through either subject's training or external stimulation — for example, with transcranial magnetic stimulation (TMS). On the other hand, this information can be used to develop brain-computer interface (BCI) aimed to assist in training [10]–[14].

In this study we concentrated on development of experimental paradigm and setup for marksmanship training in untrained subjects. We analyzed correlation between subject's fatigue and efficiency during training to be sure that we can extract brain activity related to training process.

II. Materials and Methods

A. Participants

Twenty healthy volunteers (all male, age 18-30, right-handed) with normal or corrected-to-normal visual acuity participated in the experiments. There were no subjects with history of neurological diseases and prescripted medications. The participants were asked to maintain a healthy lifestyle for 48 hours before the experiment, which included 8-hour night rest, limited consumption of alcohol and caffeine, moderate physical activity. The volunteers were informed about design of experiment, its goals, methods and possible inconveniences. They were able to ask any related questions and received exhaustive answers. All volunteers provided informed written consent before participating. The experimental studies were performed in accordance with the Declaration of Helsinki and approved by the local Research Ethics Committee.

B. Experimental setup

During the experiment we recorded a number of biological signals: electroencephalogram (EEG), electromiogram (EMG), electrooculogram (EOG), electrocardiogram (ECG), respiration activity (R). Placement of all sensors is shown on Fig. 1. All these signals were recorded with help of electroencephalograph "Encephalan-EEGR-19/26" made by Medicom MTD (Taganrog, Russia). Sampling rate for all signals was 250 Hz. For EEG recording we used 31 Ag/AgCl electrodes placed on the scalp in accordance with international scheme "10-10" (Fig. 1, white circles). EEG signals were filtered with band-pass filter (cut-off frequencies — 1 and 70 Hz) and 50-Hz notch filter in preparation for further time-frequency analysis. Other biological signals besides EEG were acquired through POLY channels of "Encephalan". For EMG recording we used 7 electrodes placed on the left bicep and back muscles (Fig. 1, yellow circles). Chosen placement for electrodes is explained by specific posture of subject during marksmanship training. EMG signals were filtered with band-pass filter (cut-off frequencies — 0.1 and 40 Hz). We used 2 electrodes above and below right eye (Fig. 1, green circles) to record EOG and 1 electrode near left clavicle (Fig. 1, blue circle) to record ECG. Respiration activity was collected via belt-shaped sensor wrapped around the subject's chest (Fig. 1, grey stripe).

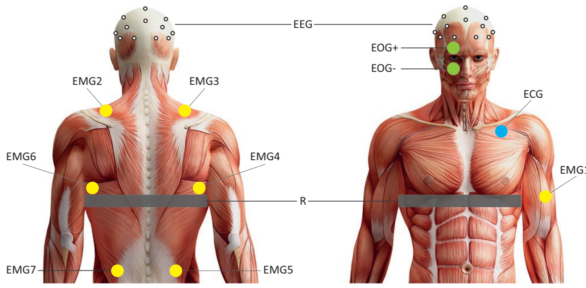

Fig. 1. Experimental setup with sensors: EEG (white circles), EMG (yellow circles), EOC (green circles), ECG (blue circle), respiration (grey stripe).

In training we used pneumatic rifle that is identical in characteristics to real firearm used by sportsmen in biathlon. The subjects were instructed about all necessary safety regulations and tips on basic marksmanship.

C. Experimental design

Experiment proceeds as follows: at first, the subject occupies required position at firing range, then the training begins. The training includes 21 trials of shooting with multidimensional fatigue inventory (MFI) [15] tests before the first and after the last trials and visual analog scale (VAS) [16] tests for fatigue estimation after each trial. One trial includes following steps: the subject receives the rifle loaded with 5 bullets from the assistant, performs 5 shots at 5 targets at any order, hands the rifle back to the assistant for reloading, passes VAS test, rests for 1 minute. MFI is a 20-item self-report instrument designed to measure fatigue. During the test the subject answers 20 questions that cover the following dimensions: General Fatigue, Physical Fatigue, Mental Fatigue, Reduced Motivation and Reduced Activity. In VAS the subject is asked to assess his/her current fatigue by subjectively choosing a value on continuous scale that conditionally ranges from "the lowest fatigue" to "highest fatigue". Results of VAS are recorded as length in mm from the start of the scale. For both tests we use tablet computer with stylus.

III. Results

We analyzed data collected through the experiment. To evaluate the subject's efficiency during the training we considered number of successful hits in each trial (N). N varied from 0 to 5 for a single trial.

Results of VAS were normalized and recalculated as characteristic V:

$$V = \frac{x - x_{min}}{x_{max} - x_{min}}, \quad (1)$$

where x — result of VAS in current trial for given subject, x_{min} — the lowest x in the whole experiment for given subject, x_{max} — the highest x in the whole experiment for given subject.

For both characteristics N and V we calculated mean values and standard deviation through all 21 subjects in each trial. The results are illustrated on Fig. 2.

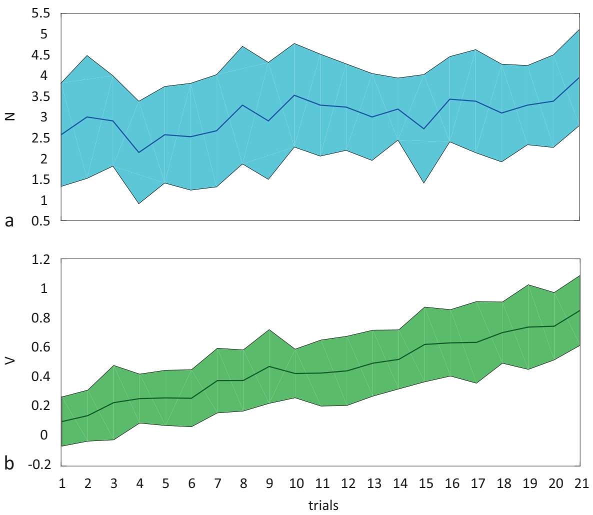

Fig. 2. Results of data analysis: dependence of number of succesful hits N (a) and normalized result of VAS V (b) from the number of trial. Solid lines show mean values while shaded areas correspond to standard deviation.

It can be seen, that both characteristics N and V demonstrate stable growth form the stat to the end of the experiment. To better show the connection between these two characteristics we calculated Pearson correlation coefficient. We showed, that correlation coefficient in this case is $R = 0.6784$ with P-value $P = 0.0007$, which correspond to strong correlation. Such strong correlation between training efficiency and fatigue implies well-designed training paradigm. On the one hand, increase in number of succesful hits reflects growth in skill, which means that training itself is efficient. On the other hand, simultaneous increase in fatigue suggests that the task is not "too easy" and the training procedure is close to optimal.

IV. Conclusion

In this work we developed experimental paradigm for marksmanship training in untrained subjects. We described and illustrated experimental setup and design. Certain characteristics N and V were introduced in order to assess subject's efficiency and fatigue during training. We analyzed these characteristics and found their steady increase through the experiment. Also we demonstrated strong correlation between subject's fatigue and efficiency during training. We speculate, that obtained resuls are the evidence of well-designed training paradigm.

We suggest that the work in this direction will continue. Fatigue assessment can be improved by adding EMG, EOG and respiration activity analysis. Additionally, EEG analysis will provide some neurophysiological characteristics to complement already considered behavioral ones — efficiency and fatigue. We believe, that such multidimentional data analysis will allow us to find "optimal" or "peak performance" brain activity corresponding to marksmanship training. The latter can be used to improve training procedure through stimultaion of desired brain activity.

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