Mechanical feedback variant in BCI

Susanna Gordleeva
Coordinating Center for Fundamental Research, National Medical Research Center for Therapy and Preventive Medicine
Moscow, Russia
Neurotechnology Departmen Lobachevsky State University of Nizhny Novgorod
Nizhny Novgorod, Russia;
gordleeva@neuro.nnov.ru

Nikita Grigorev
Neurotechnology Department Lobachevsky State University of Nizhny Novgorod
Nizhny Novgorod, Russia;
Center for Neurotechnology and Machine Learning
Immanuel Kant Baltic Federal University
Kaliningrad, Russia
andrey.savosenkov@gmail.com

Andrey Savosenkov
Neurotechnology Department Lobachevsky State University of Nizhny Novgorod
Nizhny Novgorod, Russia;
Center for Neurotechnology and Machine Learning
Immanuel Kant Baltic Federal University
Kaliningrad, Russia
na0grigorev@gmail.com

Anna Udoratina
Neurotechnology Department Lobachevsky State University of Nizhny Novgorod
Nizhny Novgorod, Russia
a.udoratina@gmail.com

Anton Kiselev
Coordinating Center for Fundamental Research, National Medical Research Center for Therapy and Preventive Medicine
Moscow, Russia

Vladimir Antipov
Coordinating Center for Fundamental Research, National Medical Research Center for Therapy and Preventive Medicine
Moscow, Russia
Center for Neurotechnology and Machine Learning
Immanuel Kant Baltic Federal University
Kaliningrad, Russia

Artem Badarin
Coordinating Center for Fundamental Research, National Medical Research Center for Therapy and Preventive Medicine
Moscow, Russia
Center for Neurotechnology and Machine Learning
Immanuel Kant Baltic Federal University
Kaliningrad, Russia

***Abstract*—The modern paradigm of neurorehabilitation of post-stroke patients includes ideomotor training using feedback of various modalities. Exoskeletons are a promising, but extremely immobile and expensive option for providing feedback. In this work, we tested mechanical feedback suitable for both hands. 6 subjects 22-33 years old took part in the tests. Training was carried out with a neural interface that controls the operation of the mechanical feedback prototype for right and left hands. The results of classification accuracy were achieved: 80±12.6% (mean±standard deviation) for the right hand; 83±10.4% for the left hand. As a result of the tests, the complex of the neural interface and the mechanical feedback showed full functional ability.**

Keywords—BCI, EEG, motor imagery, feedback.

I. INTRODUCTION

Brain-computer interface (BCI) allows a person not only to control external devices, but also to train the generation of certain states of brain activity. In this context, the technology is used for the treatment of various types of disorders, including ADHD [1]. BCIs of the motor-imaginary type use activation of the motor cortex of the brain during real or imagined movement as a control signal.

Training in motor imagery (MI) based BCI is believed to be a helpful technique in neurorehabilitation therapy of people with impaired motor functions (e.g. patients with tetraplegia, spinal cord injury) and patients with brain injuries (e.g. stroke, amyotrophic lateral sclerosis) [2]. Activation of neuroplasticity mechanisms during repetition of acts of movement (real or imaginary), accompanied by feedback, leads to the restoration of lost connections [3]. Reproduction of congruent movement by the exoskeleton, in contrast to other possible feedback options, should enhance human involvement in the process and, as a result, strengthen the mechanisms of neuroplasticity.

This paper presents a mobile version of a neurorehabilitation system for restoring motor activity of the hand. The goal of the work is to test a developed mechanical feedback via hand exoskeleton with a previously created classifier [4].

II. METHODS

A. Participants

6 healthy subjects (3 men and 3 women) from 22 to 33 years old with varying experience in working with a brain-computer interface of the motor-imaginary type took part in testing the prototype. All participants provided informed consent to participate in the research. The research protocol was approved by the ethics committee of the Lobachevsky State University of Nizhny Novgorod, Institute of Biology and Biomedicine.

B. Neurotraining complex

The prototype of the brain-computer interface neurotraining complex integrated with the hand exoskeleton consists of:

- electroencephalographic cap with a system of 8 electrodes for recording the electroencephalogram;
- encephalographic analog-to-digital amplifier with 8 channels for recording electroencephalographic signals of hand motor imagination;
- program for classifying electroencephalographic patterns of hand motor imagery;
- exoskeleton control system by recognizing electroencephalographic patterns of motor imagination;
- mobile hand exoskeleton prototype.

C. *Exoskeleton design*

The developed hand exoskeleton fits a variety of hand sizes thanks to the digital flexor housing design and four adjustable Velcro straps.

Fig. 1. Extension and flexion of fingers in the arm exoskeleton.

The arm is fixed in the exoskeleton with four tapes. Starting at the open end of the exoskeleton (Fig. 2), the first tape secures the position of the wrist, the second and third tapes secure the palm and proximal phalanges of the fingers, and the fourth tape secures the distal phalanges. During the act of bending the fingers, the bands can move relative to the hand, thereby adjusting their position so as not to cause discomfort or pain to the operator.

Fig. 2. Comparison of hand position for different hand sizes. The numbers indicate the numbering of the arm fixation tapes.

Figure 2 shows a comparison of the hand positions of people of different body types and so hand sizes in the exoskeleton. It can be seen that for correct fixation it is necessary to place the distal phalanges of the operator's fingers under the fourth tape.

All tapes should not be fully tightened so as not to injure the limb or interfere with blood flow. For patients with partial or complete loss of sensation in the limb, the procedure for fixing the arm in the exoskeleton should be checked visually for the presence of free space between the tapes and the surface of the arm (by pulling the tape, check the tension).

It was possible to achieve flexion of the proximal phalanges of the fingers by more than 30 degrees, intermediate phalanges by approximately 90 degrees, and bringing the distal phalanges to the palm - flexion by more than 150 degrees. The mechanical design of the exoskeleton body flexor is shown in Figure 3. The housing bender is driven by a DIGITAL SERVO HV7032MG servo drive.

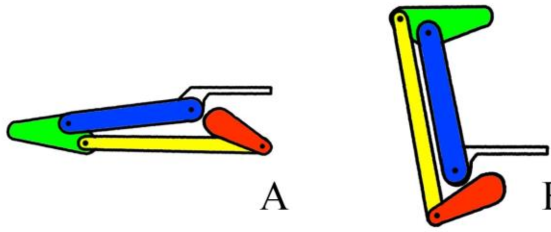

Fig. 3. Exoskeleton body flexor mechanism. A – fully extended mechanism (fingers straightened), B – maximum bent mechanism. The red part is connected to the servo.

D. *Experimental design*

The subject sat in a chair near the edge of the table, resting his left or right hand on the armrest of the chair and extending it along the table. After the subject sits comfortably (determined by oral questioning), the level of suspension of the exoskeleton and the angle of the arc of the hand position are adjusted so that the subject's hand can be relaxed and comfortably fixed in the exoskeleton.

The MCScap textile helmet was pre-installed with six Ag/AgCl lead electrodes (at positions C5, C3, C1, C2, C4, C6), one ground electrode and one reference electrode with a clip for attaching to the subject's earlobe. This helmet is made of elastic textile material that can stretch to adjust the size of your head. The standard helmet size L/M fits most adults, however for unusual cases there were sizes L and M available for larger and smaller heads respectively. The helmet was placed on the subject like a cap and secured (ensuring a tight fit to the head) with an elastic piece placed on the chin and attached to the helmet on the cheekbones using Velcro, adding an additional degree of size adjustment.

The subjects had to successively complete three tests for one hand (right or left) and, after changing the classifier training for the other hand, repeat the same for it. Due to varying levels of experience with the brain-computer interface, it was decided to use each participant's last attempt for each hand to generate statistics. In this way, subjects without experience could gain an understanding of the work and show results close to average. The order of hand testing was chosen in random order.

III. Results

During testing, five out of six subjects were able to successfully complete both sets of training sessions, for the right and left hands; one subject (S1) took part in the right-hand layout test only.

As a result, the following classification accuracy values were obtained (average ± standard deviation):

• 80±12.6% for right hand tests;

• 83±10.4% for left hand tests.

The individual results obtained for each subject are presented in Table I.

TABLE I. CLASSIFICATION ACCURACY

Hand	S1	S2	S3	S4	S5	S6
Right	80%	65%	90%	85%	65%	80%
Left	N/A	95%	70%	85%	75%	90%

IV. DISCUSSION

In this work, we tested a mobile arm exoskeleton. The results obtained, taking into account the standard deviation, exceed random classification value. When using the exoskeleton, subjects noted a convenience of placing the hand in the mount, but the unpleasant noise of the electric drive during flexion and extension of the fingers distracted them from imagination. In further development, the feedback received will be taken into account, and the design will be modified to eliminate the noise of the drive.

The exoskeleton's attachment made it possible to quickly position it on the edge of various work surfaces. Adjusting the Velcro straps for a new subject did not take much time, nor did changing the position of the exoskeleton to conduct training with the other hand.

In the future, we intend to include feedback directly while a person is performing a motor imagery to increase his involvement in the process. It is also worth measuring changes in physiological characteristics while working with the exoskeleton.

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