A «single-stimulus» brain-computer interface for sending a rapid command to a robotic arm: first results of online testing

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Brain-computer interface (BCI) is a system that analyzes brain signals and uses them to control a computer or other device. One of the most effective noninvasive interfaces is the BCI that distinguishes the P300 event-related potential wave (the P300 BCI). User of this BCI concentrates on a target stimulus associated with a certain command and mentally counts its presentations while ignoring non-target stimuli.

False activation (FA) rate is an important index of performance of a BCI that controls a robotic device. FA is an activation of an interface when there was no command from a user. Reducing FA rate is critically important because unpremeditated action of a wheelchair or a robotic arm can be potentially dangerous, especially for disabled users. Despite of quite good speed and accuracy, the original P300 BCI design is not optimal for avoiding production of an unintended commands. An exception is a special P300 BCI design for sending a single urgent command by Rebsamen et al. (2010). Their participants could issue a stop command to a robotic wheelchair in 6,0 s ($\sigma = 3,4$) with FA rate of 1,2 per minute.

Shishkin et al. supposed that speed of the P300 BCI could be increased without increasing FA rate if one uses the «single-stimulus» paradigm, in which all non-target stimuli are excluded (Shishkin et al. 2013). Based on this paradigm, the prototype of a BCI for sending an urgent command to a robotic arm was designed and investigated in the current pilot study with healthy participants. To control a robotic arm, a participant had to mentally count a stimulus that was presented on the screen until the robotic arm stopped its movement.

In the single-stimulus BCI paradigm the task for a participant is rather monotonous, and a user may easily get tired and lose optimal attention level. To prevent this adverse effect, we designed special stimuli presumably attracting a user's attention and keeping him or her engaged in the task. These visual stimuli were stylized animal faces, with eyes looking forward to the participant. A face and, especially, eyes naturally attract human attention. Rapid gaze direction recognition is an adaptive advantage, and human brain and visual system have special mechanisms for quick and robust eye detection (Langton et al. 2000). Human faces were already successfully used as stimuli in the P300 BCI (e.g., Jin et al. 2012), but we supposed that, at least in the single-stimulus design, using a human face as a stimulus presented many times may produce various undesirable effects. Ganin (2013) reported that in a P300 BCI puzzle game moving stimuli with eye(s) of living creatures on them were among stimuli which provoked fewer mistakes than other stimuli. Amplitudes of averaged event-related potentials for such stimuli were significantly higher in some participants comparing to «bad» stimuli (those that repeatedly provoked mistakes); remarkably, the latter had no eyes on them.

Eight healthy participants took part in the pilot study. From five of them, the EEG was acquired using a portable *Movicom* amplifier. For another three subjects, an *actiCHamp* amplifier was used. The EEG was recorded at 500 Hz from 7 electrodes placed at Cz, Pz, Oz, O1, O2, PO7 and PO8. Stimuli were presented using BCI2000 system (Schalk et al. 2004) with a module for «single stimulus» presentation, EEG acquisition and online processing developed in our laboratory (Nuzhdin, Fedorova 2013).

The procedure consisted of two phases. First, participants were required to count flashing stimuli on the computer screen and then to read a text, so that the classifier could be trained to distinguish between EEG epochs with attention to stimulus (counting) and EEG epochs not related to any stimuli (here, reading text). On the second phase the participants exercised BCI control with two types of feedback: sound feedback (recorded human voice saying «yes») and stopping the movement of the robotic arm. Subjects had to give a command after hearing a sound signal that was presented with interstimulus intervals varying between 16 and 32 s.

With the *Movicom* amplifier, we observed a high variability in performance, probably due to unstable system functioning under electromagnetic interference conditions. Mean response time was 5,3 s (σ=2,7), while FA rate was 0,9 per minute. With the *actiCHamp* amplifier and «active» electrodes, the performance was stable and BCI issued a stopping command, on average, in 3,2 s (σ=1,0) (figure 1), with FA rate of 0,4 per minute.

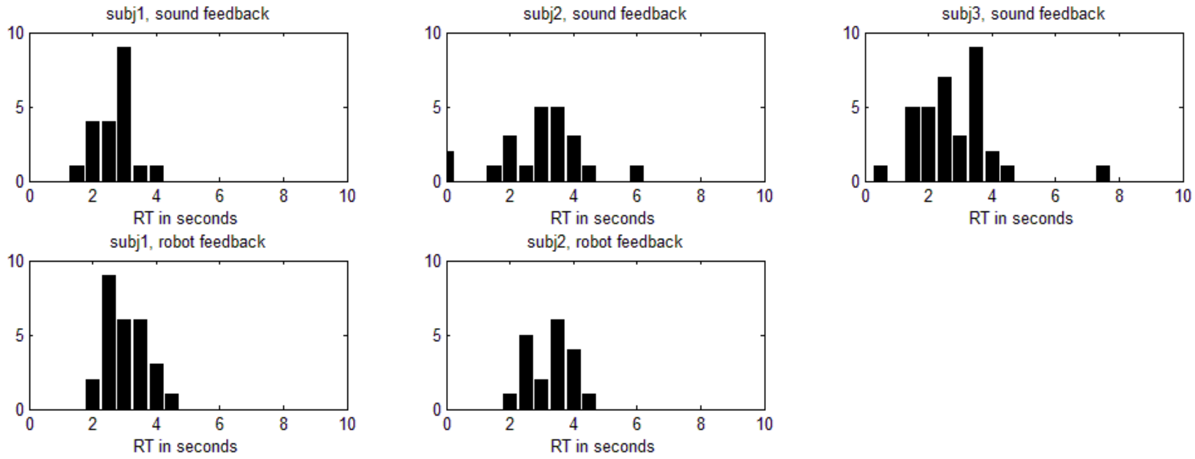

Figure 1. Histograms in the top row show RT distribution for each subject in «sound feedback» condition. Histograms in the bottom row show RT distribution for each subject issuing a stopping command for the robotic arm (Subject 3 did not receive robotic arm feedback due to technical problems). All histograms based on data acquired with the *actiCHamp* amplifier.

High speed of the interface response and low false alarm rate were observed in the current «single-stimulus» BCI design for giving a rapid stopping command to the robotic arm. Such interface could be potentially helpful in BCI based systems for high-speed and robust control of different devices for disabled and for people who cannot use manual control.

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