How quickly can we send a command to a robot using a non-invasive (eye)-brain-computer interface?

Sergei L. Shishkin[1], Yuri O. Nuzhdin[1], Anastasia A. Fedorova[1], Marat N. Faskhiev[1,2],
Albina M. Vasilyevskaya[1,2], Boris M. Velichkovsky[1]
sergshishkin@mail.ru
[1]NRC “Kurchatov Institute” (Moscow, Russia)
[2]Lomonosov Moscow State University (Moscow, Russia)

Brain-computer interfaces (BCIs) are devices for sending commands to computers using “brain signals”, such as intracortical neural firing recording or electroencephalogram (EEG). With a BCI, a paralyzed patient can communicate with other people or control robotic devices connected to a computer. Healthy people may also benefit from BCI-based new “output pathways” for their brain (Kaplan et al. 2005; Wolpaw 2007). Recent achievements in BCI technology based on intracortical recording are impressive (e.g., Collinger et al. 2013), but such technology is still associated with high risk and is very expensive. EEG based non-invasive interfacing is highly appealing as not requiring surgery, but the existing non-invasive BCIs provides the user with a rather slow and unreliable control.

Fortunately, a very significant amount of robot control can be executed in automatic mode, without any involvement of a user. In this case the user only needs to issue high-level commands, for example, by selecting them from an available set. Selection can be done at a relatively slow pace using the existing BCI technology, such as the so-called P300 BCI. Nevertheless, a user should be provided with means to quickly stop the ongoing action if something goes wrong, or if some parameters of the action should be updated, or if he or she changed his/her mind, etc. Thus, a fast BCI “switch” is needed, and it must be “asynchronous”, i.e., it should enable issuing a command at any desired time moment and avoid spontaneous generation of commands (false activations, FA) when the user does not try to execute control. Rebsamen et al. (2010) proposed a non-invasive BCI system for controlling a robotized wheelchair, which, in general, well fitted the above requirements. However, their “switch” enabled urgent stopping of the wheelchair in 6 s, which is too long for many practically significant conditions. Faster BCI response is not uncommon (e.g., 1 s or less can be achieved in BCI games – Kaplan et al. 2013), but only for “synchronous” BCIs or/and at the cost of high error rate, typically not acceptable in control of robotics. Creating fast and reliable asynchronous BCIs, at least for issuing a single command (BCI switches), is currently an important problem for BCI development.

Recently, we (Shishkin et al. 2011) proposed using the “single-stimulus” variant of the visual oddball paradigm (all stimuli are targets – see Polich and Heine 1996) to improve ergonomics of the P300 BCI calibration. Later, we noticed that stimulus presentation rate in this protocol can be made much higher than target presentation rates used in typical P300 BCI protocols, while still being comfortable for the participants and capable of evoking detectable response in the EEG. Due to high target presentation rate (in our experiments, about two stimuli per second), the user does not need to wait long for the next target. To issue a command, he or she should look at the stimulus position and count mentally each time the stimulus appears. This interface is similar to the P300 BCI modification used by Rebsamen et al. (2010) for fast stopping, but due to absence of non-target stimuli in our design detection of targets is possible at their faster presentation rate. In pilot experiments (A.A.Fedorova et al., submitted to this conference) the new “single-stimulus” BCI demonstrated two times faster response and lower FA rate compared to Rebsamen et al. results.

The new BCI, however, should be considered as a “dependent” BCI, i.e. requiring some muscle dependent control (here, the use of ocular muscles for stimulus fixation). We asked our participants to fixate the visual stimulus position but, rather than attend to them, count random sound stimuli not synchronized with the visual ones. Under this condition, the eventrelated potentials (ERP) in response to the visual stimuli were similar to ERP recorded while the participants counted them. Thus, the BCI control could be mediated primarily by fixating the stimulus. “Dependent” BCIs cannot be used by patients with most severe paralysis, who cannot control gaze direction sufficiently well. However, many of prospective BCI users can control their gaze, and they may benefit from our “single-stimulus” BCI.

To issue a command with our BCI, a user must first make a saccade to the stimulus position. Saccades can be easily detected using electrooculogram (EOG). We developed an algorithm detecting saccades to the stimulus and using information about them for improving command detection (EEG-EOG-based Eye-Brain-Computer Interface, EBCI). Indeed, some improvement was observed for EEG-EOG-based detection in an offline pilot analysis: EBCI response was about 0.5-1 s faster compared to EEG-based detection alone. We expect that further elaboration of the algorithm will lead to even better performance.

A question may arise if detection of a saccade to a designated position can be alone used for issuing a command, without applying a BCI. Such approach could enable, in principle, even faster control while not requiring recording EEG and presenting stimuli. However, detection of such events with EOG alone is impossible, while fine video-based eye tracking capable to differentiate fixation on some small area from spontaneous gazing to neighboring locations is still expensive and typically requires frequent re-calibration.

The speed of our current “single-stimulus” BCI and EBCI is limited by the need to collect EEG responses to 3-5 stimuli in order to make possible reliable detection of a user’s intent. Other non-invasive BCIs capable for fast and reliable issuing a command are motor-imagery-based BCIs, steady-state visual evoked potential (SSVEP) based BCIs and code-modulated VEP (c-VEP) based BCIs. Detection of user’s intent with motor imagery can be done without synchronization with any external events. However, for reliable performance it requires, in many users, both desynchronization and subsequent synchronization in EEG rhythms, and the latter typically needs several seconds to appear. The user of a SSVEP-based BCI needs to attend rhythmic visual stimuli, which can be not safe for some people. Recently, strikingly high performance was demonstrated for the c-VEP BCIs (Spüler et al. 2012), but their asynchronous variants have not been reported so far and it is not yet clear if such asynchronous BCIs can be effective. The c-VEP paradigm resembles our control condition (fixating but not attending the visual stimuli), although much shorter interstimulus intervals are used in the c-VEP BCIs. It seems possible that faster interfaces, with response time of less than 2 s and low FA rate, can be designed as a cross between the c-VEP-based BCIs and our “single-stimulus” EBCI. Developing even more faster (E)BCIs, however, may require more radical departure from the current approaches to BCI design.

Collinger J.L., Wodlinger B., Downey J.E., Wang W., Tyler-Kabara E.C., Weber D.J., McMorland A.J., Velliste M., Boninger M.L., Schwartz A.B. 2013. High-performance neuroprosthetic control by an individual with tetraplegia. Lancet 381: 557-564.

Kaplan A.Y., Lim J.J., Jin K.S., Park B.W., Byeon J.G., Tarasova S.U. 2005. Unconscious operant conditioning in the paradigm of brain-computer interface based on color perception. Int. J. Neurosci. 115: 781-802.

Kaplan A.Y., Shishkin S.L., Ganin I.P., Basyul I.A., Zhigalov A.Y. 2013. Adapting the P300-based brain-computer interface for gaming: a review. IEEE TCIAIG 5: 141-149.

Polich J., Heine M.R. 1996. P300 topography and modality effects from a single-stimulus paradigm. Psychophysiology 33: 747-752.

Rebsamen B., Guan C., Zhang H., Wang C., Teo C., Ang M.H. Jr., Burdet E. 2010. A brain controlled wheelchair to navigate in familiar environments. IEEE TNSRE 18: 590-598.

Shishkin S.L., Nikolaev A.A., Nuzhdin Y.O., Zhigalov A.Y., Ganin I.P., Kaplan A.Y. 2011. Calibration of the P300 BCI with the single-stimulus protocol. In G. R. Müller-Putz et al. Proc. of the 5th Int. Brain-Computer Interface Conf. Graz: Verlag der Technischen Universität Graz, 256-259.

Spüler M., Rosenstiel W., Bogdan M. 2012. Online adaptation of a c-VEP brain-computer interface (BCI) based on error-related potentials and unsupervised learning. PLOS ONE 7: e51077.

Wolpaw J.R. 2007. Brain–computer interfaces as new brain output pathways. J. Physiology 579: 613-619.