Toward a Fluent Eye-Brain-Computer Interface: EEG Negativity Marks Visual Fixations Used to Control a Game

Sergei L. Shishkin, *Member, IEEE*, Yuri O. Nuzhdin, Eugeny P. Svirin, Anastasia A. Fedorova, Yaroslav Y. Slobodskoy-Plusnin, Alexander G. Trofimov, Albina M. Vasilyevskaya, and Boris M. Velichkovsky

WHEN we are going to act on an object, our eyes automatically and effortlessly orient towards it. This is the natural basis of the technologies that enable computer and robot control using eye tracking (ET). A serious limitation for these technologies is set by the Midas touch problem: one cannot avoid spontaneous eye movements that can trigger commands unintentionally. Various means were proposed to discriminate the control and spontaneous fixations, but they require tedious efforts from the user and slow down the action [1]. To solve the problem in an unobtrusive way, the ET technology could be combined with a "passive" brain-computer interface (BCI), i.e., a BCI that not requires any action from the user. This BCI can exploit a negative potential that was observed in EEG when the participants intentionally fixated a position on a screen for 1 s to trigger an event [2]. However, it was not clear yet if EEG marker(s) would accompany fixations during diverse gaze-based control executed at many spatial locations, especially if such fixations are not required to be very long (the 1 s threshold for triggering an action can be perceived as a rather tiresome requirement).

We designed a gaze-controlled computer game *EyeLines* based on the *Lines* game [3] and conducted a study in 7 healthy participants (in accordance with the Declaration of Helsinki). The player moved balls between cells of a 7×7 field (17×17º) by subsequently fixating his/her gaze on three positions: on a "button" outside the field that switched on the control in the field; on a ball (to select it); on a free cell (to move the ball into it). Data from the *EyeLink 1000 Plus* eye tracker were analyzed online. A fixation triggered an action (highlight the button or the ball, or move the ball) when its duration exceeded a time threshold, which varied in our experiments across participants 400 to 800 ms. EEG collected within the "control" fixations demonstrated, in each participant, a negative deviation with a parietal focus. This negativity was absent in the "non-control" fixations that also exceeded the threshold but did not trigger actions as the field control function was off.

An interface that could use this negativity to detect the control fixations must operate on the single-trial basis. We assumed that the interface might be helpful even with initially low sensitivity. The commands missed by the hybrid interface can be recognized with ET alone using an additional, longer time threshold. The system will gently reinforce the user to produce well recognizable EEG markers, because they will lead to faster response. In contrast, the specificity of the interface should always be kept high, because its false alarms can be very annoying or even dangerous (e.g., in robotics).

We estimated the feasibility of the hybrid interface using control/non-control fixation sets from two participants (435/186 and 439/129 fixations, respectively) who played the game with 400 ms time threshold for 20 min each. Feature vectors were composed of the amplitudes from 30 central, parietal and occipital EEG channels downsampled to 20 Hz, 150..400 ms relative to fixation onset (150 features), and classified with the shrinkage LDA. The classifier's threshold was adjusted to ensure high specificity on the expense of sensitivity. Specificity/sensitivity for the two participants estimated using two runs of 5-fold cross-validation was 0.90/0.32 and 0.86/0.46. These results provide a preliminary evidence for the feasibility of an unobtrusive single-trial-based hybrid BCI using the EEG negativity marker of control with relatively short fixations.

References

[1] B. M. Velichkovsky, A. Sprenger, and P. Unema, "Towards gaze-mediated interaction: Collecting solutions of the Midas touch problem". In *Human-Computer Interaction: INTERACT'97 (Sydney, July 14-18th)*, Chapman & Hall, 1997, pp. 509-516.

[2] J. Protzak, K. Ihme, and T. O. Zander, "A passive brain-computer interface for supporting gaze-based human-machine interaction." In *Universal Access in Human-Computer Interaction. Design Methods, Tools, and Interaction Techniques for eInclusion, LNCS 8009*, Springer, 2013, pp. 662-671.

[3] "Color Lines", in *Wikipedia*. Retrieved December 30, 2014, from http://en.wikipedia.org/wiki/Color_Lines

This work was supported by the Russian Science Foundation Grant 14-28-00234.

S. L. Shishkin is with the National Research Centre "Kurchatov Institute", Moscow, 123182, Russia (phone: +7 (499) 196-71-00 ext. 64-97; e-mail: sergshishkin@mail.ru).

Y. O. Nuzhdin, E. P. Svirin, A. A. Fedorova, A. M. Vasilyevskaya and B. M. Velichkovsky are with the National Research Centre "Kurchatov Institute", Moscow, 123182 Russia.

E. P. Svirin and A. M. Vasilyevskaya are also with the Faculty of Biology, Lomonosov Moscow State University, Moscow, 119991 Russia.

Y. Y. Slobodskoy-Plusnin is with the Institute of Higher Nervous Activity and Neurophysiology, Russian Academy of Science, Moscow, 117485 Russia.

A. G. Trofimov is with the National Research Nuclear University MEPhI, Moscow, 115409 Russia.