Tactually-Evoked Event-Related Potentials for BCI-Based Wheelchair Control in a Virtual Environment

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Abstract. Brain-computer interface (BCI) based wheelchair control may be of value for those not able to operate a wheelchair with a joystick. Technology depending on visual or auditory input may not be feasible as these modalities are dedicated to processing of environmental stimuli (e.g. recognition of obstacles, ambient noise). Herein we thus validated a BCI based on tactually-evoked event-related potentials (ERP) in N = 15 healthy participants. Participants navigated a virtual wheelchair through a building and eleven participants successfully completed the task of reaching 4 checkpoints in the building. We conclude that most participants achieved good wheelchair control and dynamic stopping was of high value for tactile ERP classification.

Keywords: brain-computer interface (BCI), tactile P300, event related potentials (ERP), wheelchair control, dynamic stopping

1. Introduction

People with severe disabilities, e.g. due to neurodegenerative disease, depend on technology that allows for accurate wheelchair control. Brain-computer interfaces (BCI) have been suggested as a control channel for those not able to operate a wheelchair with a joystick (for review, e.g. [Millán et al., 2010]). Herein we explore use of tactually-evoked event-related potential (ERP) based BCIs [Brouwer and van Erp, 2010]. Tactile stimulation has the advantage that it does not use a modality that is also needed for processing of non-BCI related input, e.g. observation of the environment while steering a wheelchair (visual modality) or processing of ambient noise (auditory modality).

2. Material and Methods

Fifteen healthy participants took part in this study (12 female; mean age: M = 21.8 years, SD = 2.9, range 18–27 years). EEG was obtained from 16 passive Ag/AgCl electrodes at positions Fz, FC1, FC2, C3, Cz, C4, CP1, CP2, P7, P3, Pz, P4, P8, O1, Oz, O2 and sampled at 512 Hz (BCI2000 software, g.USBamp amplifier).

2.1. Tactile stimulation and experimental design

Tactile stimulators (C2 tactors; Engineering Acoustic Inc., USA) were positioned at four body locations that represented navigation directions (placed on left upper leg: move left; right upper leg: move right; belly: move forward; lower neck: move backward) and participants focused their attention on the stimulator they intended to select.

The experiment comprised one calibration run, two online copy tasks and finally an online navigation task through the virtual building. (1) Calibration was performed with 30 stimulations per trial and eight trials (each tactor was the target twice). If estimated classification accuracy was below 100%, calibration was repeated once. (2) After calibration, participants performed two copy tasks with adjusted number of stimulations (procedure for selecting the number of stimulations as described in [Kaufmann et al., 2012]). One run was performed with static number of stimulations; one run incorporated a dynamic stopping method with the same maximum number of sequences. This allowed estimating the influence of dynamic stopping on selection accuracy and duration for tactile ERP-BCIs. (3) The BCI was then tested in a virtual environment. Participants were asked to steer a wheelchair through a building and reach 4 checkpoints. The wheelchair was equipped with shared control sensors to avoid object collisions or sliding along walls.

3. Results

Performance estimated offline from calibration data was high ($N = 14$: 100%, $N = 1$: 87.5%; calibration repeated once for $N = 5$ participants). Fig. 1 displays accuracy and duration of target selection for the three online tasks.

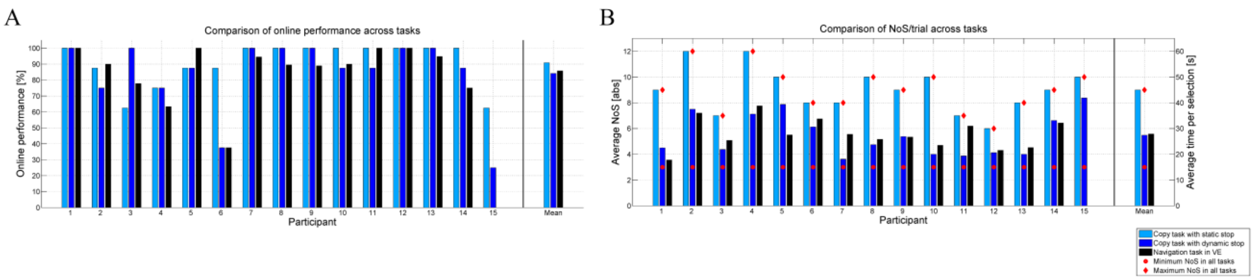

Figure 1. *(A) Performance in online tasks, i.e. two copy tasks and one navigation task (B) Average number of stimulation sequences and time per selection needed in online tasks.*

(1) In the copy spelling task with static number of sequences average accuracy was $M = 90.8\%$ ($SD = 13.7$, range 62-100%) and 9 of 15 participants performed without errors. (2) Performance did not significantly decrease when introducing dynamic stopping ($Z = 0.70$, $p = 48$; $M = 84.2$, $SD = 23.4$), i.e. most participants maintained the performance level achieved with static number of sequences. However, performance for two participants severely decreased; for one even to chance level. Analysis of selection durations displayed great benefit of the dynamic stopping method in that the number of stimulation cycles was significantly decreased ($Z = 3.81$, $p < 001$). (3) Participant 15 did not perform the navigation task as her performance decreased to chance level when using dynamic stopping in the copy task. Thus, $N = 14$ participants performed the navigation task through the virtual building. Importantly, $N = 11$ of 14 participants reached the final checkpoint and four of them made no error. Although the navigation task can be regarded as more complex than a simple copy task, performance did not significantly decrease in the virtual environment ($N = 14$, $Z = 0.33$, $p = 74$). Shared control sensors were rarely needed, $N = 8$ participants did not need it at all. $N = 3$ participants, however, could not successfully finish the navigation task.

4. Discussion

Tactually-evoked ERPs for wheelchair control are promising in that most of the participants reached the final checkpoint in the navigation task and shared control was only needed by a few of the participants. Overall performance was high and selection times could be significantly decreased with dynamic stopping.

Tactile ERP-BCIs may thus offer a valuable alternative to motor imagery based BCIs considering the findings that about 30% of BCI users do not gain sufficient SMR control (e.g., [Guger et al., 2009]). However, performance varied considerably between participants implying the need for testing larger groups and particularly those in real need to allow for generalization of results. Recent results of a case study with a patient in total locked-in state are promising in that tactile stimulation evoked reliable and pronounced ERPs [Kaufmann et al., 2013].

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