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USING A ONE-DIMENSIONAL CONTROL SIGNAL FOR TWO DIFFERENT OUTPUT COMMANDS IN AN IMPLANTED BCI

S. Leinders[1], E.G.M. Pels[1], M.J. Vansteensel[1], M.P. Branco[1], Z.V. Freudenburg[1], M.A. van den Boom[1], M. Vermaas[2], E.J. Aarnoutse[1], and N.F. Ramsey[1]

[1] Brain Center Rudolf Magnus, University Medical Center Utrecht, Department of Neurology and Neurosurgery, Utrecht, the Netherlands

[2] Donders Centre for Neuroscience, Radboud University Nijmegen, Nijmegen, the Netherlands

E-mail: s.leinders@umcutrecht.nl

ABSTRACT: As part of the Utrecht NeuroProsthesis (UNP) project, a late stage ALS patient has been implanted with a BCI system that allows her to communicate at home. The BCI system converts short, transient changes in brain activity from the motor hand area into ‚brain-clicks', which are used to control spelling software. On request of the participant, we added the option to use the control channel for producing a second output command, giving her the possibility to call for attention at any time. Here, we show that the user is able to produce sustained increases in activity for this purpose and that these signal changes can be clearly distinguished from the transient changes used as ‚brain-clicks'. We conclude that it is possible to use a one-dimensional control signal based on motor hand activity to produce two different output commands.

INTRODUCTION

The Utrecht NeuroProsthesis (*UNP*) project aims to provide locked-in patients with an implanted BCI system for communication, which they can use at home without the presence of research staff. So far, one woman with late stage ALS has been implanted with the UNP system and uses it at home [1]. Although being able to speak one's mind freely (in the case of someone with locked-in syndrome: spell) is a vital aspect of communication, another important component is the ability to call for attention at any moment, for example when there is physical discomfort or pain. On request of our participant, we aimed to implement this additional feature into the UNP system.

The UNP system is a click-based system with one control channel. It converts short and voluntary changes in brain-activity from the motor hand area into ‚brain-clicks', which can be used to navigate through a custom-made interface, called the UNP menu, based on BCI2000 software [1,2]. Within the UNP menu, the user can navigate to and control commercial spelling software (*Communicator 5, Tobii Dynavox*), play brain games, and change settings.

To make sure that the additional feature to call for attention is always available, i.e. from any part of the UNP menu, including the spelling software and the games, a second control signal is required. Earlier observations (see the Supplementary Appendix of the original article [1], Figure S4-D) indicated that the user was able to generate longer periods of increased activity (here referred to as *sustained activity*). We aimed for this sustained activity to activate an escape pop-up menu, containing ‚*call-caregiver*', ‚*return to main menu*' and ‚*continue*' buttons. After activating the pop-up menu, the user could then use regular clicks to select the different options within the pop-up menu.

Importantly, some key selections within the UNP menu require a 'double click' (i.e. two regular clicks shortly after one another), to prevent accidental selections of menu options that can be difficult to correct (e.g. a settings change). For accurate control of these double clicks *and* the activation of the escape pop-up menu, these two types of neuronal activity profiles need to be clearly distinguishable from one another. Here, we investigated: 1) the optimal duration of the break between double clicks, aimed at minimizing unwanted escape menu pop-ups during double clicks, while keeping double clicks as fast as possible; 2) the optimal duration of the sustained activity for the escape pop-up menu activation.

MATERALS AND METHODS

Participant: Our participant is a sixty year old woman with late stage ALS. She is locked-in and communicates with eye blinks (yes - no), an eye tracker, and/or the UNP system.

Hardware and Data: Data was recorded with the implanted UNP system. Electrocorticography surface electrodes (Resume II ®, Medtronic) are located subdurally on the left M1 hand knob area and leads are subcutaneously tunneled to an implanted amplifier/transmitter device (Activa ® PC+S, Medtronic), which is located subcutaneously under the left clavicle [1]. Brain activity from one bipolar electrode pair was converted into power data over two frequency bands (low frequency band, *LFB:* center frequency 20 Hz; high frequency band, *HFB*: center frequency 80 Hz) in the Activa ® PC+S device and

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streamed wirelessly at a rate of 5Hz to an antenna connected to a research laptop running BCI2000. To obtain the control signal, both channels were normalized in our BCI2000 filter pipeline, after which the z-scored LFB channel was subtracted from the z-scored HFB channel [1]. All reported data was recorded at our candidate's home.

To allow for a second output command, we implemented a new filter called the escape filter into our existing BCI2000 pipeline. This filter runs in parallel with the regular click filters [1], but settings are set such that it only activates during sustained increases of the control signal. When this filter is activated, the escape menu pops up.

Prior to this escape project (and thus the quantification of escape related sustained activity) our participant already used the escape filter at home. Initial settings were found empirically (i.e. we changed settings online, based on user feedback), using regular click settings as a starting point. In this period before the escape project, the length of escapes (i.e. how long the control signal needs to be above threshold for escape activation) was adjusted several times based on home-use experience. A fixed escape threshold of 0.35 (based on the regular click settings) however always seemed to work well, and was therefore used as the default threshold value in this project. (For more information on determining optimal regular click settings, please see our previous paper [1, Figure S6].)

Validation Task: We used a custom-made BCI2000 task called the MultiClicks task to address our research questions. Task layout was as follows: A cursor was presented at a fixed location at the horizontal and vertical middle of the screen. The background moved from left to right at a fixed pace. Different colours in the background instructed the participant to relax or to produce transient or sustained activity by attempting to tap the fingers of her right hand (Figure 1). More specifically, our candidate attempts flexion of ring finger and thumb until they 'touch' (of course, they do not actually touch because they do not move), and then extension of both fingers. Our participant reports that one such sequence of attempted movement takes approximately one second. Attempted movement is repeated as long as active cue lasts.

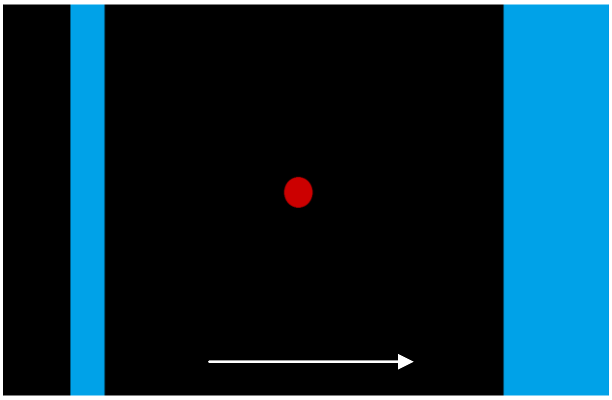

Figure 1: Screenshot of task. The background moved from left to right (direction of arrow) at a fixed pace, while the red cursor remained in the middle of the screen. When the cursor crossed a blue block, the participant was instructed to attempt finger movement. When the cursor crossed a black block, she was instructed to rest. Width of blue and black blocks varied across conditions. From left to right side of screen is 10 seconds.

The MultiClicks task was performed four times in one session with the same set of conditions each time. Conditions comprised single clicks, double clicks, and sustained activity. The break between double clicks ranged from one to five seconds, and the length of the sustained activation condition varied between four and seven seconds (all in steps of one second). To prevent potential false positive escape activations during regular clicks, four seconds was chosen as the shortest escape duration, because we have previously seen that the increase in control signal associated with short active cues of 1 second (required length of regular clicks) can last up to 3 seconds [1, Figure S4-D]. Every condition was presented twice in each run. All runs lasted approximately four minutes and the duration of the inter-trial interval (i.e. rest blocks) was seven seconds. Condition order was randomized. No visual feedback was presented. The subject was instructed to time her mental strategy based on the visual cues, and not to anticipate.

RESULTS

The participant was able to generate broad and sustained peaks in the control signal for up to 7 seconds (the longest period of sustained activity tested, Figure 2). For all durations of sustained activity tested, LFB power decreased shortly before cue onset and increased after cue offset (beta rebound). Moreover, HFB increased sharply at cue onset, and stayed high (although with somewhat more signal variability than LFB) until cue offset. Although the candidate was instructed not to anticipate, there did seem to be some anticipation in brain activity shortly before actual cue onset, especially in the LFB band (Figure 2).

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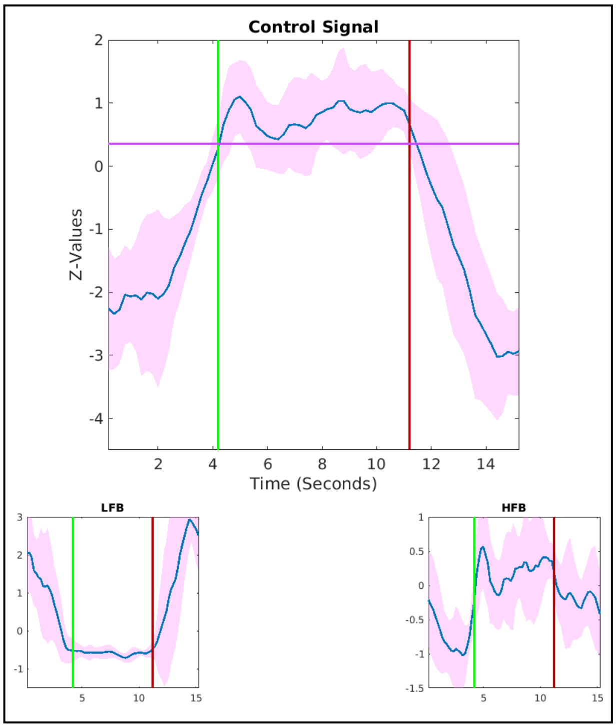

Figure 2: Mean trace (± standard deviation in pink) from the 7 second sustained activity condition, based on all trials from the presented four runs. Top plot: Control signal normally used for clicking (based on both LFB and HFB power, see methods for details). Bottom left: LFB signal. Bottom right: HFB signal. All plots have z-values on the y-axis and time in seconds on the x-axis. Vertical green and red lines indicate cue on- and offset, respectively. The horizontal purple line in the top graph indicates threshold for detecting sustained activity (0.35).

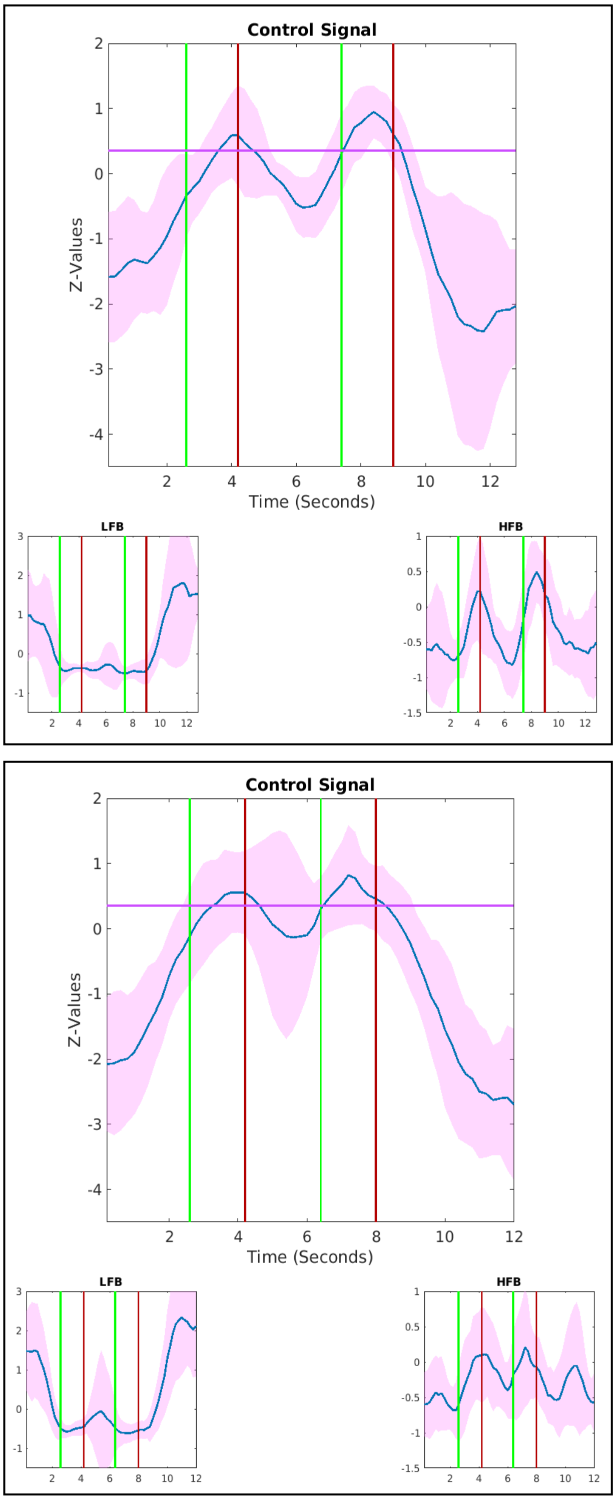

Figure 3: Double click plots with mean trace and standard deviation fill, based on all trials from the presented four runs. Top panel: 3-second break condition. Bottom: 2-second break condition. Both panels contain main plot with control signal, and two subplots with LFB and HFB signal. All plots have z-values on the y-axis and time in seconds on the x-axis. On- and offset of both clicks are plotted (vertical green and red lines, respectively). The horizontal purple lines in the control signal graphs indicate threshold for detecting sustained activity (0.35).

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With regard to the break between double clicks: The participant was able to generate two separable clicks with intervals of 5, 4 and 3 seconds (Figure 3, top panel). However, a 2 second break between two clicks did not consistently allow a sufficient decrease of the control signal below the threshold (Figure 3, bottom panel). As a result, the control signal of double-click trials with a 2 second break may be mistaken for sustained activity.
Interestingly, the decrease of the control signal between two clicks with 3 second separation could be mostly attributed to a transient decrease in HFB amplitude. In contrast, the LFB signal stays low during both clicks comprising double clicks and also during the break between those clicks, and does not contribute to the separation of the clicks in the 3 second break condition. In the 4 and 5 second break conditions however, LFB increases during the break, contributing to the separation of the two clicks.

DISCUSSION

As part of the UNP project we explored the separability of control signal changes associated with double clicks and sustained activity. From the data we concluded that: 1) the user can produce sustained increases in the control signal for at least seven seconds; 2) the user is able to produce two clearly separable clicks when the break between the clicks is at least three seconds.
The optimal duration of sustained activity required for activating the escape pop-up menu is based on two considerations: 1) the length of sustained activity should be as short as possible, so the user can activate the escape as fast as possible; 2) the length of the sustained activity should be long enough for it to be distinguishable from double clicks, to prevent double clicks without a clear dip between clicks (which is uncharacteristic based on presented data, but possible) from activating the escape pop-up menu.
For the current user we found that 5.6 seconds of sustained activity is feasible. Our user chose this length based on required effort and reliability of escape activation when using a 3 second break strategy during double clicks. Since we fixed these settings during the escape project (December 2016), they have not been changed. Our participant can now reliably activate the escape pop-up menu using a sustained activity length of 5.6 seconds, while minimizing false positive escape menu pop-ups by applying a 3 second break between double-clicks.
Double clicks with an interval of 3, 4 and 5 seconds all showed a clear decrease in the control signal between the two clicks. Since we wanted to optimize speed, we focused on a 3 second break between double clicks for this project. Moreover, our participants‘s home-use settings use a length of 5.6 seconds for sustained activity although she can produce longer sustained activity (up to 7 seconds at least). From these two points we concluded there is a range of usable settings beyond the current settings: we could increase both the sustained activity length and the break in double clicks in case our user is no longer satisfied with her home-use settings in the future. These changes might increase reliability at the cost of speed.
By using a one-dimensional control signal to produce two different types of outputs, we have expanded our implanted BCI’s functionality. Moreover, the MultiClicks task developed for this project can be used with future candidates to determine a range of usable double click and escape settings early on in the UNP project. Because an escape if probably a useful feature for all users, this is an important point. Sustained activity is currently used to activate an escape pop-up menu, which allows our user to select a call-caregiver button as the first option. The other two options in the escape-menu are resuming the current application or quitting to the main menu. Sustained activation could be used for other purposes, depending on a user’s wishes and needs, such as reversing scanning order within spelling software or jumping to a next category or page (this could increase spelling speed).

CONCLUSION

A one-dimensional control signal recorded from a bipolar pair of subdural ECoG electrodes allows for two different types of output commands based on short and sustained activity increases. The newly added sustained activity feature allows our candidate to activate an escape button at any time.

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