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WORKING MEMORY AS A CONTROL SIGNAL IN A FULLY IMPLANTED BRAIN-COMPUTER INTERFACE

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ABSTRACT: Voluntary control of brain activity using working memory can be used to control a BCI. Here we present data on an ALS patient with a fully implanted BCI with ECoG electrodes placed over left dorsolateral prefrontal cortex. This area is a versatile brain region involved in cognition. During several runs of a task where sustained activity in the high frequency band (HFB) is required to control a cursor in the direction of a target, the subject initially reached above chance performance, but in later runs reached performance up to 96%. The subject also performed a task in which a short rise in HFB (click) had to be generated to select an icon in a matrix. The subject was able to generate clicks, although with many false positives. We conclude that both sustained and short activity can be generated with a working memory strategy. The improvement on the cursor control task suggests that the task became more automated.

INTRODUCTION

It has long been established that one can control a Brain-Computer Interface (BCI) with activity from the motor cortex, both with EEG and ECoG signals. The latter signal has a more precise localization and higher amplitude. A demonstration of BCI control with activity from the motor cortex, using ECoG signal, was presented recently by our group: an ALS patient was implanted with a fully implantable BCI with ECoG electrodes on the motor cortex [1]. A rise in high frequency band (HFB) activity during a short attempted movement was used to generate a click. This click was translated to a selection in a spelling program to enable spelling for the patient.

The motor cortex, however, is not the only cortical area which can be controlled voluntarily. We have shown previously that sustained ECoG activity from the dorsolateral prefrontal cortex (dlPFC), an area active during working memory tasks, such as mental calculation, can be used for BCI control [2]. Also, clicks generated from dlPFC were demonstrated in an ECoG study [3].

In addition to the electrodes placed over motor cortex, also electrodes over dlPFC were placed. Two reasons motivated placing electrodes over dlPFC: Primary, it was not known whether the signal over motor cortex would deteriorate as a result of the disease and secondary, the dlPFC is a higher order cortex where training may cause a quicker automatization of BCI control. We here present results on using sustained and short signal changes in dlPFC for BCI control.

MATERALS AND METHODS

BCI implant: The subject is a 60-year-old woman with late stage ALS in a locked-in state. She was implanted in October 2015 with four subdural electrode strips (two on the left motor cortex, two on the left dlPFC; Medtronic LLC, Minneapolis, MN) on the basis of prelocalisation with fMRI. Extension cables were tunneled through the neck and externalized through the abdominal skin. After an electrode selection procedure, during a second surgery three days later, the strips with highest correlation with a screening task (both attempted movement and mental calculation) were connected to an Activa® PC+S amplifier/transmitter device (Medtronic), which was placed infraclavicularly in the thorax. See for more detail on the procedures [1]. The bandpass filtered signal (HFB, center frequency 65 Hz) is received by a unit and send to a computer running custom software, based on the BCI2000 software package, which is capable of presenting real-time visual feedback of the brain signal to the subject.

Tasks: Data was gathered during research sessions twice a week at the home of the subject. Multiple runs of a working memory task were performed during a session, not all sessions contained working memory runs.

Two working memory tasks are presented to the subject: First, a Cursor Control Task for sustained activity which provides feedback on the HFB (Fig. 1). The HFB is translated to velocity in y-direction, in x-direction velocity is a fixed number. Trials lasts 2-6s. The instruction was to move the cursor up by counting backwards in steps of e.g. 7 from a random starting number, in order to reach the upper target at the right and move the cursor down with rest to reach the lower target.

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Initially, both the random starting number and random step size were displayed at the beginning of each trial. Accuracy is calculated by the number of targets hit divided by the total number of targets, chance level is 50%. Second, a Click Task is presented, where a mole is presented at a random location in a matrix with icons (Fig. 2). First, the rows were highlighted in a stepwise manner and the instruction is to make a click to select the row where the mole icon is. Subsequently, the icons in that row are highlighted and the subject is instructed to select the icon with the mole. Feedback to the user is given with a color change of the highlight with a correct selection and removal of the mole. The next trial starts with the mole in a new random position. The clicks are generated when the power in the HFB exceeds an empirical threshold for 1.2 s.

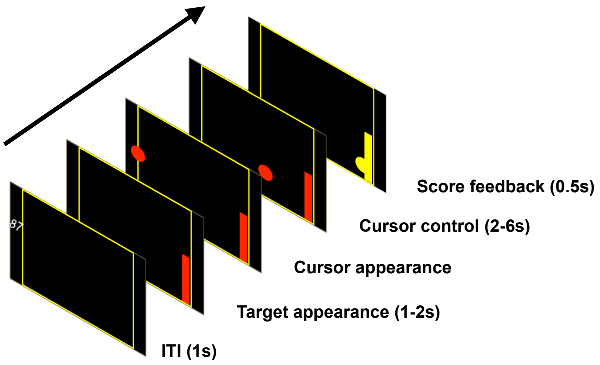

Figure 1. The Cursor Control Task provides feedback to the subject on the dlPFC activity. Note that a random number is given as a starting point for counting backwards.

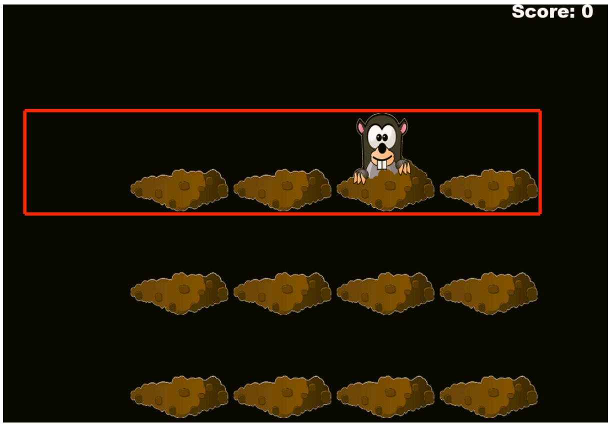

Figure 2. Rows of icons were highlighted sequentially at a fixed pace (red box) during which it could be selected by a click. Individual icons of the selected row were subsequently highlighted and could be selected with a second click. Goal was to select only the mole.

RESULTS

The subject was able to perform the Cursor Control Task with a working memory strategy.
Initially, accuracy was low (60%), but after a few sessions of training an accuracy of 90% was reached (Fig. 3). The subject reported in later sessions that display of a starting number was not needed anymore, thinking of a number already resulted in a higher dlPFC activity. She experimented with this in the sessions 31-40, with lower performance as a result. After returning to the previous strategy, accuracy increased to a maximum of 96%. After session 84 the display of the starting number was not needed anymore. Average accuracy after session 84 was 80.6%.

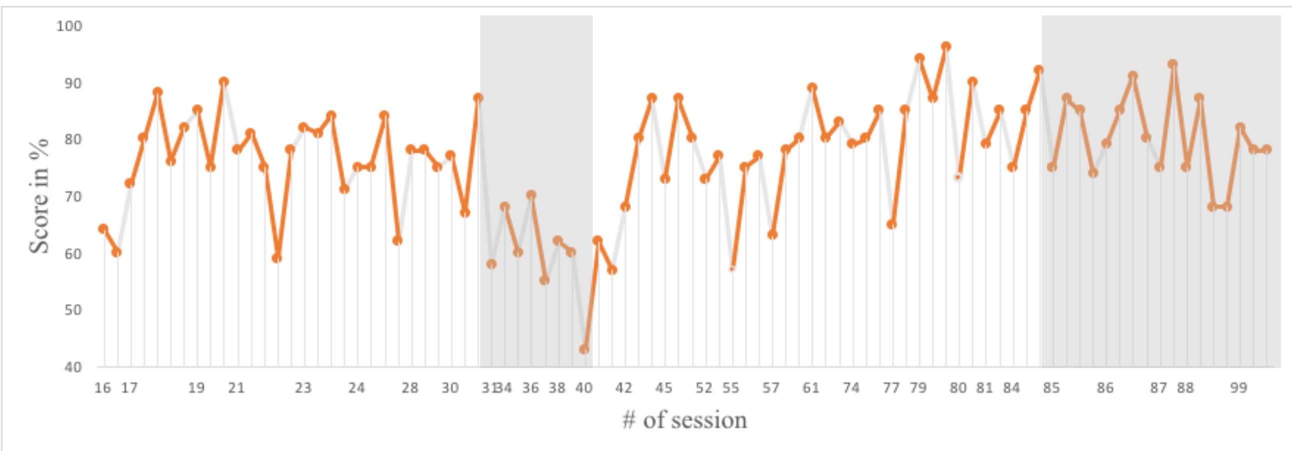

Figure 3. The performance of all runs of the Cursor Control Task with this subject. The lower performance in sessions 31-40 (grey background) can be attributed to a change in mental strategy: no starting numbers for counting backward. After session 84 this strategy without starting numbers (grey background) was used again, but now with high performance.

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The subject performed 13 runs of the Click Task during 3 sessions. The subject was able to generate a click with a working memory strategy. Accuracy was 63%, with chance level of 50%. The low accuracy can be attributed to the high number of false positives. However, she was able to generate a short rise in HFB (Fig. 4).

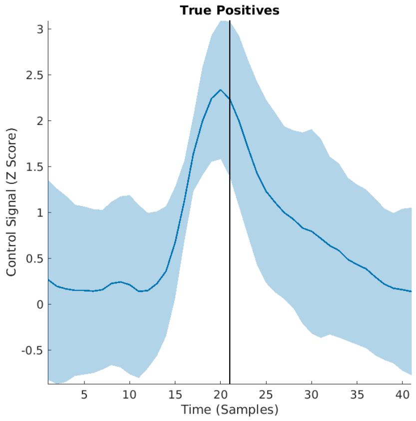

Figure 4. The mean HFB (±SD) activity over runs (after normalization) relative to the time the activity was translated into a true positive click. Samples of HFB are recorded every 200ms. Note a clear rise in HFB 1200ms before the click and 4s fall after the click.

DISCUSSION

The data demonstrate that the subject was able to use a working memory strategy for BCI control. Continuous control in a Cursor Control task was shown before [2]. In this study the subject had the opportunity to perform many more runs than reported before. According to the subject some automatization takes place over time, which correlates to the higher scores, even without a starting number, in later sessions. This is in line with the flexible nature of the dlPFC. In addition, the subject reports that her strategy for generating clicks shifted from actual counting backward to thinking of a number. This may also cause the irregular timing of the working memory clicks and false positives during highlight of the icon just before the mole. Irregular timing in working memory BCI control was found also in a previous study [3]. The number of false positives diminished in one run by a more active rest strategy. With more training we expect improvement, especially on the timing.
Working memory controlled BCI might be more valuable as an addition to motor control, than as a replacement. However, using working memory clicks for spelling might be feasible at a slower speed than motor clicks.

CONCLUSION

A subject with an implanted BCI was able to use a working memory strategy for BCI control, both in a task with sustained activity and in a task with short clicks. Feedback of the subject that she could perform the task without starting numbers suggests that the task becomes more automated.

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