Motor imagery-based 1-dimensional BCI using subdural electrocorticography

Made available May 2016

Original paper

Wander JD, Sarma D, Johnson LA, Fetz EE, Rao RPN, Ojemann JG, Darvas F. Cortico-cortical interactions during acquisition and use of a neuroprosthetic skill. PLOS CB, 2016 (in press).

Abstract of the original paper

A motor cortex-based brain-computer interface (BCI) creates a novel real world output directly from cortical activity. Use of a BCI has been demonstrated to be a learned skill that involves recruitment of neural populations that are directly linked to BCI control as well as those that are not. The nature of interactions between these populations, however, remains largely unknown. Here, we employed a data-driven approach to assess the interaction between both local and remote cortical areas during the use of an electrocorticographic BCI, a method which allows direct sampling of cortical surface potentials. Comparing the area controlling the BCI with remote areas, we evaluated relationships between the amplitude envelopes of band limited powers as well as non-linear phase-phase interactions. We found amplitude-amplitude interactions in the high gamma (HG, 70-150 Hz) range that were primarily located in the posterior portion of the frontal lobe, near the controlling site, and non-linear phase-phase interactions involving multiple frequencies (cross-frequency coupling between 8-11 Hz and 70-90 Hz) taking place over larger cortical distances. Further, strength of the amplitude-amplitude interactions decreased with time, whereas the phase-phase interactions did not. These findings suggest multiple modes of cortical communication taking place during BCI use that are specialized for function and depend on interaction distance.

Materials and methods

Subjects

This dataset includes electrocorticographic (ECoG) data from ten human subjects (1 female, mean age 26.9y). Each of these subjects were all patients with intractable epilepsy who were implanted with platinum sub-dural ECoG grids (AdTech, Racine, WI) for the clinical purpose of seizure focus localization and resection. These subjects were monitored for between four and ten days before removal of the arrays and surgical resection of the seizure focus. During this time the subjects participated in multiple recording sessions, separated over one to three days. All procedures were carried out within the University of Washington Regional Epilepsy Center, either at Harborview Medical Center or Seattle Children’s Hospital after informed consent was obtained. For children under age 18 parental consent was obtained along with consent from the child (age 14 or above) or assent of the child (age 7-13). The protocol was approved by the Institutional Review Board at both institutes.

The physical makeup (number and arrangement of electrodes) and implant location of all grids were based on clinical indication. Arrays were either 8x8, 6x8, 4x8, or 2x8 grids or 1x8, 1x6, or 1x4 strips with 2.4mm diameter exposed recording surface and a 1cm inter-electrode distance.

Table 1 – Demographic and task performance information of subjects. Abbreviations: right (R), left (L), frontal (F), parietal (P), temporal (T), occipital (O). Entries in the BCI type column refer to whether the subject was performing motor imagery of the tongue or hand.

SID	Gender	Age	BCI type	Trial count	Coverage	Focus location
S1	M	29	Tongue	84	R-F/T	R posterior T/O
S2	M	27	Tongue	108	R-F/P/T	R F
S3	M	14	Tongue	39	L-F/T	L F
S4	M	22	Tongue	97	R-F/P/T	R mesial T
S5	F	26	Tongue	164	R-F/P/T	R F
S6	M	54	Hand	120	L-T	L T
S7	M	11	Hand	68	L-F	L anterior F
S8	M	29	Hand	110	R-F/P/T	R F
S9	M	19	Hand	89	R-T	R mesial T
S10	M	38	Tongue	50	R-F/T	bilateral - no resection

ECoG data collection

Experimental recordings were conducted at the patient's bedside without disruption of the clinical recordings. Either Synamps2 (Neuroscan, El Paso, TX, USA), or g.USBamps (GugerTec, Graz, Austria) sampled at 1000 Hz or 1200 Hz respectively were used for recording. ECoG potentials were recorded with respect to a reference electrode placed on the subject's scalp. All stimulus presentation, real-time signal processing, and BCI feedback were conducted using the BCI2000 software suite.

Cortical reconstructions and anatomical labeling

Cortical reconstructions were performed using previously published methods [1,2]. In brief, the reconstructions were generated as follows: Preoperative MRI was coregistered with postoperative CT imagery using the Statistical Parametric Mapping software package [3]. Reconstructions of the pial surface were then generated from the preoperative MRI using Freesurfer (freely available for download at http://surfer.nmr.mgh.harvard.edu/) and custom Matlab (The Mathworks, Natick, MA) code. Electrode positions were then estimated in the postoperative CT and projected onto the reconstructed pial surface following previously described methods [2].

The BCI task

The subjects were given as many opportunities as they wished to perform the 1-D, two-target right-justified box task. The task is discussed in our previous publications [1,4] and is reviewed in the following paragraphs. See Fig. 1 for a depiction of the task.

The BCI task consists of four phases: rest, targeting, feedback, and reward, lasting, 1 second, 2 seconds, 3 seconds, and 1 second respectively.

During execution of the BCI task, the subject is presented with one of two targets, occupying either the top half or the bottom half of the right-most edge of the screen. After a fixed targeting interval of one sec, the cursor appears on the left edge of the monitor and travels to the right at a fixed horizontal velocity, such that the duration of the feedback period is fixed (3 sec all subjects but S6, who had a feedback period of 2 sec). The subject controls the vertical velocity of the cursor by modulating high-gamma (HG) activity at the controlling electrode (CTL); performance of motor imagery causes the cursor to travel up and remaining at rest causes the cursor to travel down. Their objective is to complete each trial with the cursor in the specified target area for that trial. A sub-portion (approx. 70-90 Hz; to reduce real-time signal processing constraints) of the HG activity recorded at CTL is mapped to vertical cursor velocity using a simple linear decoder that was trained in the first set of trials. During this training period, the users were still presented with visual feedback of a cursor that was being driven by HG activity at CTL, so cursor trajectories can be unpredictable during these initial trials. Information as to during which trials this training was occurring is embedded into the data format, as explained below.

Prior to performing the BCI task, subjects were instructed to on both the phases of the task, and cognitive approaches to performing motor imagery. They were instructed to imagine gross motor movement, thinking both of generating the motor movement itself, but also to imagine the sensation of performing that movement. Experimenters were present during all recordings and verbally instructed subjects not to perform overt movements. Over the learning process, subjects were allowed to develop their own motor imagery strategies to achieve the task.

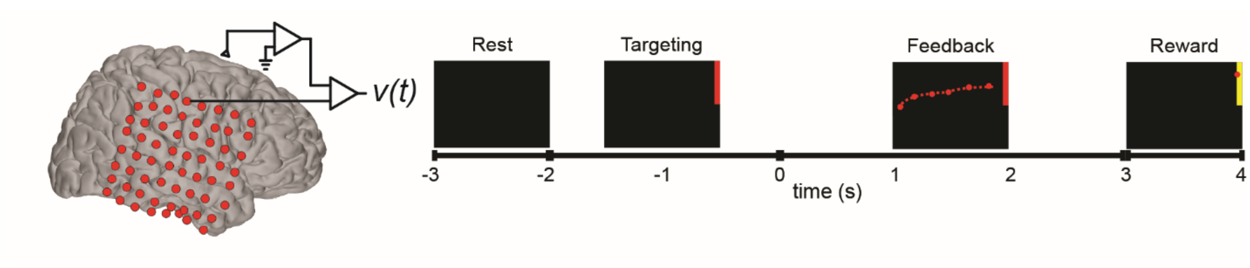

Figure 1 - BCI task overview. Overview depicts the spatial scale of the ECoG grids, as well as the phases and timing of the BCI task. Subjects were presented with a target occupying either the upper (up target;

depicted) or lower half (down target) of the right-most edge of the screen and had 3 sec to control the vertical position of the feedback cursor such that it ended the trial in the target area.

Data format

Each data file corresponds to the data from a single subject, thus there are ten data files in total. Each file is in the .mat format with the following structure:

- **sid** [string] – a unique identifier corresponding to each subject
- **bad_channels** [1 x M double array] – a list of channels that were determined to be bad, through visual inspection.
- **electrode_locations** [channels x 3 double array] – coordinates of each electrode location as determined by the localization method described above. Coordinates are with reference to subject-specific cortex.
- **control_channel** [1 x 1 double] – channel that the subject was using for BCI control.
- **cortex** [1 x 1 struct] – struct collection of vertices and faces suitable for visualization of each subject's cortical surface, reconstructed as described above. The cortical surface can be plotted using the MATLAB function patch.m.
- **recordings** [1 x N struct array] – N is the number BCI2000 'runs' completed by the subject. A run can contain one or more trials. Each element of the array contains the following fields
    - **signals** [samples x channels double matrix] – the raw samples corresponding to a complete run
    - **states** [1 x 1 struct] – a collection of time-variant states of the task, which includes the following (all are [samples x 1] and either uint8, uint16, or double).
        - TargetCode – encodes the position of the target. When the value is zero, no target is displayed, when the value is one, an 'up' target is displayed, when the value is two, a 'down' target is displayed.
        - ResultCode – encodes the position of the cursor during the feedback portion of each trial. When the value is one, the cursor terminated the trial in the 'up' target's area, when the value is two, the cursor terminated the trial in the 'down' target's area. When ResultCode == TargetCode, the trial was successful.
        - Feedback – encodes whether or not the subject actively had control over the cursor for that moment.
        - CursorPosX (when available) – encodes the normalized x-position of the cursor in the workspace. Ranges between zero and one. A value of zero corresponds to the left side of the workspace, one to the right.
        - CursorPosY (when available) – encodes the normalized y-position of the cursor in the workspace. Ranges between zero and one. A value of zero corresponds to the bottom of the workspace, one to the top.
    - **parameters** [1 x 1 struct] – a collection of static parameters of the task, which includes the following (all are [1 x 1]).
        - SamplingRate – the sampling rate of the system in Hz.

- PreRunDuration – the duration of the pre-run interval in seconds.
- PreFeedbackDuration – the duration of the pre-feedback interval in seconds.
- FeedbackDuration – the duration of the feedback interval in seconds.
- PostFeedbackDuration – the duration of the post-feedback interval in seconds.
- ITIDuration – the inter-trial interval in seconds.
- MinRunLength – the minimum length of a run in seconds.
- Adaptation – an indicator of whether the system was adapting to the subjects's control signal during this run. A value of zero indicates that normalization was turned off, a value of two indicates that the system was attempting to normalize the control signal to have zero mean and unit variance. This setting was typically turned on during the first few runs to allow the BCI to adapt to the subject's control signal. See (http://www.bci2000.org/wiki/index.php/User_Reference:Normalizer) for more information.

Contact

Please contact Jeremiah Wander (jdwander@uw.edu) or Jeffrey Ojemann (jojemann@uw.edu) if you have additional questions regarding this dataset.

References

1. Blakely T, Miller K, Zanos S, Rao RPN, Ojemann J. Robust, long-term control of an electrocorticographic brain-computer interface with fixed parameters. Neurosurg Focus. Blakely T, Miller K, Zanos S, Rao RPN, Ojemann J 2009 Jul; 27(1):E13.

2. Hermes D, Miller K, Noordmans HJ, Vansteensel MJ, Ramsey NF. Automated electrocorticographic electrode localization on individually rendered brain surfaces. J Neurosci Methods. Hermes D, Miller K, Noordmans HJ, Vansteensel MJ, Ramsey NF 2010 Jan 15; 185(2):293–8.

3. Penny W, Friston K, Ashburner J, Kiebel S, Nichols T, editors. Statistical Parametric Mapping: The Analysis of Functional Brain Images [Internet]. 1st Editio. 2006 [cited 2012 Oct 26].

4. Wander JD, Blakely T, Miller K, Weaver KE, Johnson L a., Olson JD, et al. Distributed cortical adaptation during learning of a brain-computer interface task. Proc Natl Acad Sci. Wander JD, Blakely T, Miller K, Weaver KE, Johnson L a., Olson JD, et al. 2013 Jun 10; 110(26):10818–23.