
An fNIR Based BMI for Letter Construction Using Continuous Control

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Abstract

A long term goal of assistive technology research is to build creative expression applications where subjects can extemporaneously express themselves. Sketch drawing is one form of creative expression. In this work, we demonstrate the usability of a brain-machine interface (BMI) for expression using a letter drawing task. We describe empirical results that represent a first step toward assistive applications for creative expression.

Keywords

Brain-machine interface, Hemodynamic response, Biometric interfaces, Disability access, Interaction concept design, and Assistive technologies, fNIR.

ACM Classification Keywords

K.4.2 [Computers and Society]: Social Issues – Assistive technologies for persons with disabilities; H.5.2 [Information Interfaces and Presentation]: User Interfaces- Interaction styles, Evaluation/Methodology, Screen design, User-centered design.

Introduction:

An important goal of assistive technology research in brain-machine interfaces is to improve the quality of life for disabled subjects through improved communication and interaction. Subjects who suffer from severe brain trauma or disease such as

Amyotrophic Lateral Sclerosis (ALS) require brain-machine interfaces to communicate. Interfaces that allow for creative extemporaneous expression allow subjects more freedom in expression, and therefore represent a compelling application for brain-machine interfaces. Freeform drawing is one such system. Drawing or painting programs are a common graphical application available on most systems and serve as the initial motivating analog to this system. Further, the ability to create simple sketches and glyphs would enhance the user experience for locked-in subjects as well as provide additional information for caregivers. The purpose of this work is to investigate the viability of a single sensor BMI in a creative expression application.

General-purpose assistive technology introduces some constraints on the types of sensors that may be used. Assistive interfaces should be noninvasive and portable. Sensors must be able to be worn without any implant procedures, and the system must be able to move to suit subject environment. Both electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS) satisfy these constraints [2]. In comparison, fNIRS often produces less noisy signals than EEG and are often more easily configured than EEG sensor arrays. While signals are often less noisy, the hemodynamic response is much slower to detect than electrical field responses in the brain. The study presented here explores the use of this relatively slow response signal in a near real-time setting.

fNIRS for Control

fNIRS is a multi-wavelength optical spectroscopy technique that can be used to sense cortical activity through the measurement of hemodynamic changes

[1]. Sensors placed on the scalp consist of emitters and detectors. Emitters produce light in the near-infrared spectrum with limited scattering while the detector detects the amount of reflected light passing through cortical regions of the brain. Most biological tissues are relatively transparent to light in the near infrared range from 700nm to 900nm. Emitters typically are used within this wavelength window, because the absorption factors between oxygenated and deoxygenated blood are most easily differentiated [1]. Using the Beer-Lambert equation to compute intensity, we can recover the relative oxygenated blood concentration for a cortical region.

Hemodynamic responses are elicited by evoking mental tasks that activate a target region. For instance, language production tasks activate inferior frontal gyrus regions in the left hemisphere. Using fNIRS sensors over this region, we detect evoked activation when subjects are asked to complete syntactic tasks such as sentence production or spelling. Relative deactivation

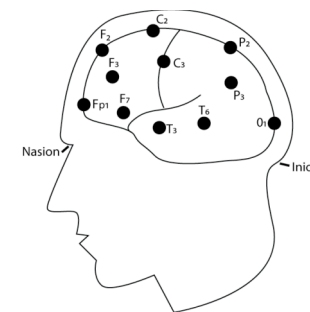


Figure 1. Profile perspective of the left hemisphere with 10-20 system locations plotted. Task related activation for language production tasks has been noted in the inferior frontal gyrus (F7).

occurs when a control task is evoked that activates a spatially distant region of the brain. For example, mental rotation activation is often spatially far from inferior frontal gyrus. In binary decision settings using fNIRS, subjects are asked to activate or rest (deactivate) for a fixed amount of time to indicate intent (yes or no). These sequences are more commonly referred to as “rest-active” or “active-rest” trials. The purpose of this study is to investigate the viability of this signal in continuous control tasks.

Free style drawing application

For a successful drawing system, a BMI must react to the continuous signal produced by the observation system. With respect to fNIRS, the continuous O₂ value is used to make inferences of user intent. A simple one-to-one mapping of the observed signal is not possible in this setting; signal noise due to environmental as well as participant factors limits the information contained in the raw signal. Another important consideration is the fact that inferring user intent yields one-dimensional data. The drawing pane is two-dimensional, and any additional interface functionality only adds to this representational complexity. To overcome the ill-posedness of the objective, we enforce some constraints on the possible direction the line will extend and make some initial assumptions. First, the point always starts in the middle of the drawing pane. Second, the starting state of the drawing point is assumed to draw down from the midpoint. Curves will always turn clockwise; the curvature of the line is a function of the input observations of the fNIRS device.

Drawing letters

We are interested in measuring subjects’ ability to control line drawing using the interface. Letter drawing

is a drawing task where the objective is to draw a letter most closely matching a template. A tracing template like those used in handwriting exercises are used to measure performance. Using these templates as the ground truth objective, we compare subjects’ ability to activate and deactivate to draw letters. Furthermore, extemporaneous letter drawing is itself a compelling application for assistive technology.

Drawing interface

The actual interface consists of the drawing pane that is common in conventional drawing programs. As the line is being drawn, the output line color encodes the inferred activation level: red indicates maximal activation, violet indicates minimal activation. This feedback information indicates the inference state of the BMI and assists users in changing mental tasks for desired results.

Preliminary Pilot Study

In the letter-drawing task, near real-time inference of user intent from the activation signal is crucial to providing feedback for successful trials. To determine which aspects of the signal may be used for this purpose, we consider a data driven preliminary study. We recorded activation data from subjects using a fixed activation sequence, where participants were asked to repeat a sequence of “activate-rest” trials. Between trial blocks, the duration of activation and rest segments of trials was manipulated (15s and 30s). The time courses of activate and rest trials for each duration were averaged and compared (see Figure 2). In this data, no preprocessing filters were applied to trial data. The data suggest a simple inference rule based on the slope of the least squares linear regression function over fixed subsequences of the trial

data: positive slope indicates activation, negative indicates rest, and near flat slope indicates no change

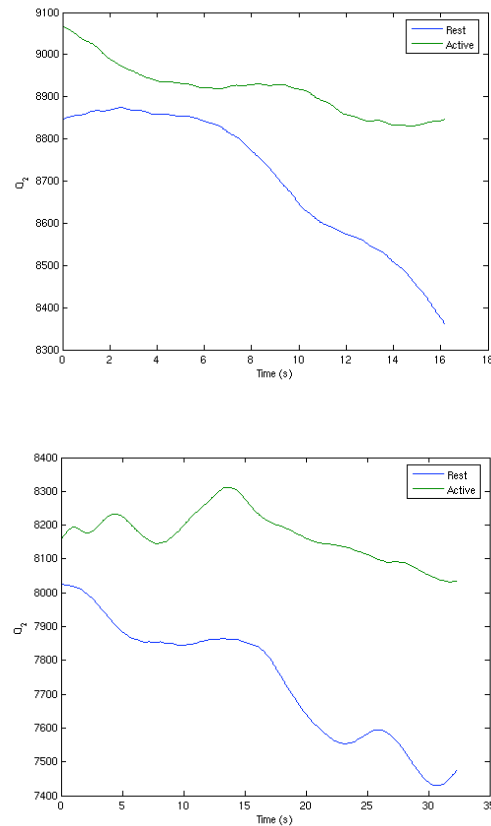


Figure 2. Averaged trial time-course of oxygenation concentration for trials types. The 15s duration time course (top) for active-rest and rest-active (green, blue respectively), and the 30s duration time course (bottom) for the same trial types.

from the previous activity. The regression line also serves as a simple smoothing mechanism for noise.

Methods

We designed the testing process to include the preliminary pilot study and a letter drawing study. The same participants were used in both studies, and individual participant data from the pilot were not used as prior information in the experiment.

Participants

Four participants including one female participant were tested with ages 30 ± 7 years. All the participants were right handed as determined by the Edinburgh handedness inventory. All participants had normal hearing and vision with no history of neurological or psychiatric illness.

Test Procedure

For both the preliminary pilot and the experiment, participants were seated in a comfortable chair to view the stimulus display. The fNIR sensor was fixed on the scalp so that the sensors were pointed to the left inferior frontal region of the brain, located approximately over F7 in the 10-20 system. The sensor was calibrated to appropriate light detection and signal quality levels to ensure proper placement and signal detection before data gathering. Participants were then briefed about the tasks; they were informed that activation is achieved by subvocal counting tasks and deactivation is achieved through imagined spatial manipulation of three-dimensional objects.

Stimuli and Task for Preliminary Pilot Study

Each participant completed two trial blocks consisting of 50 "active-rest" trials. The first trial block used a sequence duration of 15 seconds; the second used a 30

second duration. Within each trial, participants received an auditory cue indicating “activate” or “rest”. The activate cue indicated the trial start; the rest cue indicated when to change mental tasks.

Stimuli and Task for Letter Drawing Study

The goal of the experiment was to trace a letter in the drawing pane. The tracing template was rendered in the background of the drawing pane to indicate to subjects which stimulus to draw. Participants were asked to perform activation tasks in order to draw a straight line, and deactivation tasks to draw a curved line. The initial state of the line direction was always down and the curvature was always clockwise.

The trial blocks consisted of repeated trials of two letters of the alphabet (“J” and “C”). Each participant completed 10 trials of each letter of the alphabet. Visual feedback about the extent of activation was provided to help guide the participant to perform subsequent tasks in order to construct the letter according to the displayed template. Again, the line color indicated the inferred activation level and informed participants on task performance. The experimenter controlled the offset of the stimulus.

Error Detection

Error was measured by the amount of deviation between the letter drawn by the participant and the

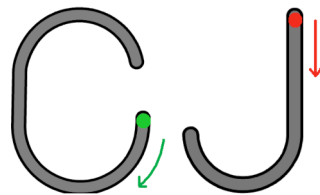


Figure 3. Experimental letter templates where dots indicate the starting state of the drawing program and arrows indicate starting state direction of the line.

template letter presented on the screen. The deviation is quantified by the Root Mean Square (RMS) of the distances of the sample points in the trial alphabet from the corresponding points in the template. The RMS values that we obtained in our study also serve as a direct indication of the difficulty of the task with higher values for alphabets with more number of transitions (from a curve to a straight line or vice versa).

Results and Discussion

Figure 4 shows sample trial performance for the two letter stimuli. In these images, the line color is what participants saw during the task indicating the relative inferred activation. In the case of “J” trials, the initial start state was to draw a line straight down. In order for participants to approximate the letter, they were required to change the activation state to complete the curve. In the case of “C” trials, the initial start state was to draw a curve, and participants were required to change the state to a straight line then back to a curve state to best approximate the task letter. The starting activation state was augmented using an initial bias. For instance, for letter “C”, the activation bias was toward curvature. The RMSE for each subject in both task letters are shown in the following table.

Table 1: Sample mean RMSE for each subject.

	1	2	3
J	161.93	143.17	152.68
C	88.92	124.80	122.27

The RMSE serves as an indication of the relative difficulty in task completion. Task letters were selected for the relative activation changes needed to approximate the letter. An implicit objective of the letter-drawing task where a regression method predicts user intent is to explore the feasibility of the interface in a fixed task. In a post-hoc analysis across subjects, many “C” trials, while approximating the task letter in

RMSE, do not contain activation changes (i.e. a constant curve was drawn). While maintaining constant activation in a particular brain region is difficult, the challenge facing letter construction is one of relatively rapid state changes. Further, the onset latency of the BOLD response itself remains a challenge to near real-time response.

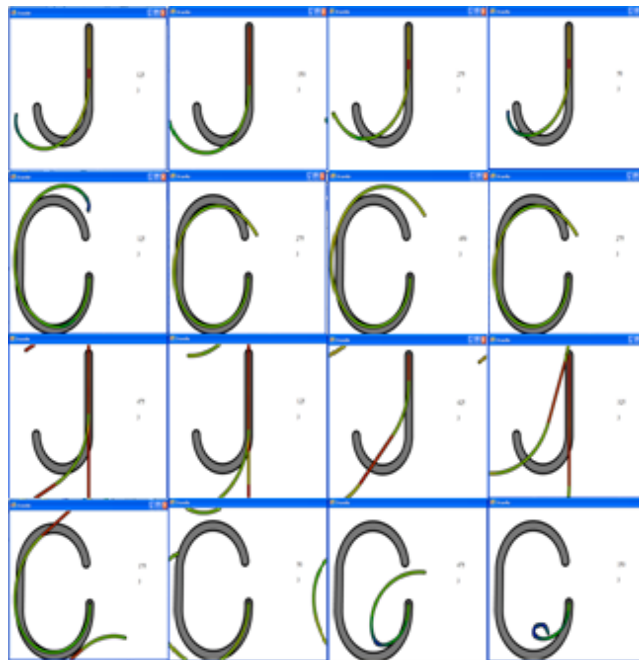


Figure 4. Example trials: 1st and 2nd row contains successful J and C construction respectively; the 3rd and 4th rows contain unsuccessful J and C construction respectively

Future Work

The results presented here represent an initial study of the efficacy of letter construction using a fNIRS-based

BMI. We expect a complete study that tests all letter construction efficacy and accuracy to be successful. Several enhancements were noted during data gathering that will inform more sophisticated inference mechanisms for the interface. Currently, we are working with a more general interface that removes *a priori* biases in the drawing start state.

Finally, combining the continuous control shown here with discrete choice control will allow for a more robust drawing experience. Using additional sensors and mental tasks to represent discrete choices addresses the additional representational complexity. Target tasks include color palette selection and brush selection as well as other functionality common in conventional drawing interfaces.

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