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Spelling with cursor movements modified by implicit user response

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Introduction: Typically, BCI systems are controlled via invoking asynchronous commands or by strategically attending to task-specific stimuli. We explore an approach defined by implicit control [1] which uses error-related responses [2,3] and targets the user's innate task-relevant processing.

Materials, Methods and Results: The cursor was the BCI's primary task element as it navigated through a 7x7 grid, moving in one of eight potential directions (cardinal or diagonal neighbor) every step until reaching a corner. Each corner of the grid was assigned a subset of the alphabet, pruned after each corner hit. The probability distribution of the next cursor movement was modified by the user's response with a Bayesian update rule. Thus the cursor movement was both the primary task and the probe stimulus.

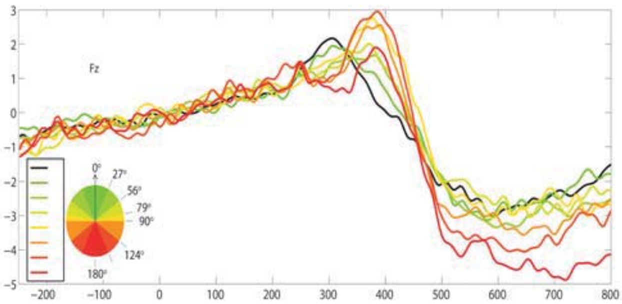

Fig. 1: Grand average plot of voltage for the 8 angular groups. Based on cursor movement's angular deviance from target corner direction.

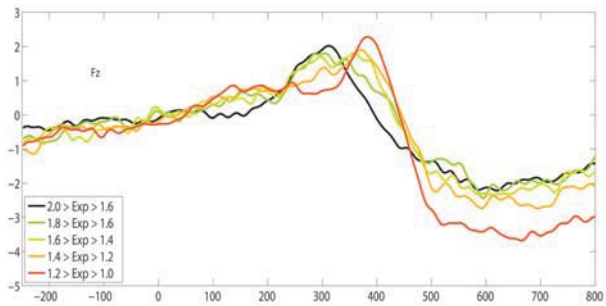

Fig. 2: Grand average plot of voltage for 5 expectation groups. Reflects distance from hyperplane distinguishing classes, with 1.5 lying between.

Participants were instructed to evaluate each cursor movement as "good" or "bad", with respect to reaching the letter they wanted to select. For classification, movements were grouped by angular deviance from the direct path to the target corner (0° deviance "good"; > 135° "bad".) A regularized LDA classifier was trained on an average of 250 of these trials (from 900) of training data per subject, using BCILAB's windowed mean's paradigm (150-700ms epoch, 11 windows of 50ms periods). The participants' response patterns varied systematically relative to angular deviance (Fig. 1). Additionally, the trained classifier was sensitive to this relationship (Fig. 2). For each subject, there was a significant correlation (averaged $R = -.3237$ [± .1003], $p < 1.0e\text{-}7$ for all subjects) between increasing angular deviance and decreasing classifier output. The off-line classifier's per jump error rate for participants (n=18) was 30.88% (± 6.11%). Analysis entailed a leave one out training scheme for the "good" and "bad" trials; the resulting model was then applied to trials within a more liberal hit class (angular deviance $\leq 30^{\circ}$).

Discussion: Removing explicit stimuli and replacing them with embedded probes enables an implicit form of control [1]: users are not actively communicating control commands, but instead, are merely evaluating the cursor movements. Their event-related potential reflects implicit evaluation of the degree of mismatch between the system's activity and the user's desired end state and presents a new form of human-computer interaction.

Significance: We present a BCI system using an implicit control signal, wherein the user's evaluation of task conditions informs the system. Interaction is implicit; the subject does not need to perform any discrete action to indicate a target. (Supported by NSF grants IIS 1219200, SMA 1041755, IIS 1528214)

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