THE THOUGHT TRANSLATION DEVICE (TTD) AS A MULTI-FUNCTIONAL BCI: COGNITION DETECTION, EEG-FEEDBACK IN FUNCTIONAL MRI AND COMMUNICATION

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The goal to achieve Brain-Computer-Communication (BCC) in severely paralyzed patients is not solely devoted to the question of how to design classification algorithms, feedback paradigms or spelling procedures. Two other important questions are focused in the current version of the Thought Translation Device (TTD) as a BCI for clinical and research purpose which utilizes physiological control of slow cortical potentials (SCP) to provide BCC:

1) Before successfully teaching a patient totally unable to communicate by muscular activity (locked-in syndrome) to self control his or her own brain signals, a knowledge about the state of consciousness and cognitive abilities needs to be obtained. For this purpose, a diagnostic Cognition Detection System (CDS) has been developed as a further extension of the TTD. The CDS consists of a freely expandable set of event related EEG experiments such as the well known oddball paradigm with "oddity" appearing on various levels of the brain's information processing. The CDS investigates the ability of a patient to discriminate between, e.g., words, pseudo-words and her own name; between syntactically and semantically well-formed sentences on the one hand and sentences well-formed syntactically but ill-formed semantically on the other; or between "matching" and "non-matching" enumerations of ordinal numbers. This is done by recording auditory or visually evoked potentials and then carrying out a discriminant analysis of EEG patterns. Therefore, features for statistical analysis such as discriminant analysis and significance tests have been included in the TTD. A set of seven experiments with an event-related design and auditory stimuli have been developed to examine patients in a vegetative state or with locked-in syndrome for their cognitive abilities. From a technical point of view, implementing a stimulus-response paradigm within the framework of a multi-tasking oriented computer operating system introduces a latency problem, i.e. the problem of not being able to precisely determine the point in time where stimulus presentation will actually take place. Despite the TTD running on MS-Windows®, stimulus presentation latency is small compared to the accuracy required for analyzing evoked potentials. The TTD-CDS-system provides a powerful combination of diagnostic and brain-computer-communication applications in a single system. The first results are presented from one patient in a vegetative state who can be regarded as cognitively intact by analyzing the data of six event related experiments, which were carried out with the CDS-system. For a comparison, the data of the experiments from one healthy person are shown.

2) As not all human subjects learn to obtain SCP self control, functional MRI can be used as a method to investigate the mechanisms underlying SCP self control in the brain because it provides high spatial resolution. Therefore the TTD was modified with respect to the amplifier, the synchronization with the MRI scanner and the feedback paradigm to be applicable in an MRI environment. Several subjects, trained successfully and non-successfully outside the MRI, will be investigated with this combined EEG-feedback/fMRI method. Before the simultaneous EEG/fMRI recording is carried out subjects are trained to achieve self-control over SCPs in terms of evoking a positive or negative potential shift at the vertex on command. First results from one well trained subject show activation in the blood oxygen level during the task to produce cortical negativity primarily at the vertex (bilateral), the precuneus and the inferior temporal regions. During the positivity task, at the vertex (bilateral, mainly gyrus postcentralis), the precuneus, and additionally at the right temporal pole and inferior parietal left an activation occurred. Deactivation was only found during positivity and involved widespread visual areas, the medial orbital

frontal cortex and the superior parietal cortex. Comparisons between learners and non-learners help clarifying the basic mechanisms in physiological control of the EEG.

FEEDBACK TO IMPROVE DETECTION OF EVENT-RELATED POTENTIALS IN ELECTROCORTICOGRAM

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Introduction

Subjects given appropriate feedback have learned to modify the mu rhythm (Wolpaw, et al., 1991) or increase event-related desynchronization (ERD) and event-related synchronization (ERS) (Pfurtscheller, et al., 1998) in their electroencephalogram (EEG) for the purpose of operating a direct brain interface (DBI). Feedback for the improvement of DBI operation in electrocorticogram (ECoG) has not previously been demonstrated, however.

The University of Michigan DBI is based on the detection of event-related potentials (ERPs) in human ECoG. Research subjects are patients in epilepsy surgery programs who have subdural electrodes implanted for clinical purposes unrelated to the research objectives. Previously reported off-line detection experiments (Levine, et al., 2000) have relied on off-line processing. As a consequence, no feedback has been provided and movement-related ERPs (instead of preferred motor imagery ERPs) have been required for determination of movement onset and detection accuracy. .

Methods

The UM-DBI first generation ERP acquisition, analysis and training system allowed selection of a feedback template and then provided the subject with feedback on the quality of subsequent ERPs (Rohde, et al., 1999). The feedback experiment session involved a template collection block of 50 repetitions of an action and 6 feedback blocks each containing 25 repetitions of the same action. Sessions lasted no more than 2 hours. Feedback was based on a comparison between the incremental change in the signal-to-noise ratio (SNR) of the ERP template caused by the addition of the current ERP (Rohde, et al., 2002) and the average change in the SNR of the ERP template during the previous template collection or feedback block. The feedback was in the form of a deflection of a vertical green bar on a computer screen approximately 2.2 seconds after movement onset (Rohde, 2000). The subject was instructed to try to get the bar to go all the way to the top of the computer screen. The maximum possible height of the feedback bar was the average change in the SNR from the previous block scaled by 0.2 to 2.

Results

Data is reported from six subjects who participated in 11feedback experiment sessions. ERP templates with SNR's above 3.0 were found for all subjects. Dramatic improvements in the template SNR between the baseline template collection block and subsequent feedback blocks were found for 3 subjects. For these subjects the SNRs improved from 3.5 to a maximum of 7.8, from 4.8 to a maximum of 10.5 and from 5.1 to a maximum of 8.0 over the six feedback blocks. Of the three subjects who were able to improve the SNR of their ERPs, only one had a corresponding improvement in the accuracy with which the ERP could be detected using cross-correlation based template matching. This subject was able to improve the detection from 79% hits and 22% false positives in the template collection session to 100% hits and 0% false positives in the 6^{th} feedback session. In two subsequent sessions with this subject, template SNR improved in the first feedback blocks, but then rapidly decreased.

Discussion

These results indicate that improvements in the SNR of ERPs related to actual movement and in the resultant detection accuracy are possible over a relatively short period of time given only simple feedback, however, performance variability needs to be further explored. The next generation system, which is under development, will provide online feedback based on the cross-correlation value used for detection, rather than an indirect measure of "quality." Also, feedback will be provided continuously (instead of only at the time of the actions) to promote the reduction of false positives as part of improved detection accuracy. Online feedback will also permit experiments using imagined movements.

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