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An Improved Cognitive Brain-Computer Interface for Patients with Amyotrophic Lateral Sclerosis

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Introduction: Brain-computer interfaces (BCIs) are often based on the control of sensorimotor processes, yet sensorimotor processes are impaired in patients suffering from amyotrophic lateral sclerosis (ALS) [1]. Previously, we devised a novel paradigm that targets higher-level cognitive processes to transmit information from the user to the BCI [2]. The current work describes a refined version of this paradigm. We instructed five ALS patients (table 1) and eleven healthy subjects (6 female, mean age 28 years ± 7.5) to either activate self-referential memories by thinking of a positive memory, or to focus on a mental subtraction task, while recording a high- density electroencephalogram (EEG). We argue that both memories [3] and mental calculations [4] are likely to modulate activity in the default mode network (DMN) without involving sensorimotor pathways.

Table 1. ALS Patient Data

Patient	P1	P2	P3	P4	P5
Age	75	54	NA	51	59
Sex	M	M	M	F	F
ALS-FRS-R[1]	42	48	33	12	0

[1] Revised ALS Functional Rating Scale [5]

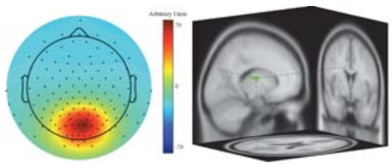

Figure 1. Topography of sources that represent the precuneus

Material, Methods and Results: Subjects performed four experimental blocks in a single session. Each block consisted of ten trials in which they were asked to continuously subtract a small number from a large number, and ten trials in which there were asked to think of a positive memory. The command appeared in the center of the screen and was simultaneously read out by a text-to-speech engine. For the subtraction trials, both the large number and the small number were randomly chosen. Each trial began with 5.5±0.50 seconds rest and ended after 35 seconds. ALS patients were only asked to perform two blocks. We restricted our offline analysis to the α-range of the spectrum, as this band is associated with self-referential processing [5]. We removed EMG confounds by employing independent component analysis. By using the topography in figure 1, we aimed a linearly constrained minimum variance beamforming algorithm [6] at the precuneus region, the hub of the DMN. The α-bandpower of the beamformed signal was then used in a leave-one-trial-out cross-validated support vector machine with a linear kernel to estimate the accuracy in discriminating the activity-patterns. Table 2 shows the classification accuracies for ALS patients and healthy subjects.

Table 2. Classification Accuracies for Patients and Healthy Subjects.

P1	P2	P3	P4	P5	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
97%	60%	90%	43%	77%	100%	75%	100%	40%	85%	35%	85%	85%	80%	65%	50%

Discussion and Significance: The current study aimed to show that healthy subjects and ALS patients in various stages of the disease are able to use a cognitive paradigm for BCI control. Using a linear classifier, we were able to successfully distinguish a self-referential from a non-self-referential condition, with an average decoding of 73%, separately for both healthy subjects and ALS patients. A one-tailed Wilcoxon signed-rank test rejected the null-hypothesis of a median classification accuracy on chance-level (50%) at p = 0.0015 for the combined subject groups. The presented work could serve as a novel tool which allows for simple, reliable communication with patients in late stages of ALS.

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