Communication for people with amyotrophic lateral sclerosis (ALS): A P300 brain-computer interface (BCI)

F Nijboer 1, EW Sellers 3, T Matuz 1, A Furdea 1, J Mellinger 1, M Jordan 1, U Mochty 1, J Kaiser 2, JR Wolpaw 3, N Birbaumer 1, A Kübler 1

1 University of Tübingen, Germany; 2 University of Frankfurt, Germany; 3 Wadsworth Center, Albany, USA

Introduction

Noninvasive brain-computer interfaces (BCIs) record electroencephalographic (EEG) signals from the scalp and translate them into control commands. The goal of BCI research is to provide non-muscular communication for people who are severely paralyzed. The purpose of this study is to further evaluate the possibility of P300-BCI use by patients with ALS. We aim specifically at answering the following questions:
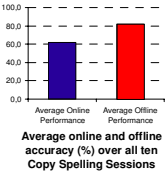
1) Can ALS-patients achieve adequate performance (over 70 % correct) with the P300 BCI? (see copy spelling)
2) Can these patients then use the BCI for communication? (see free spelling) Furthermore, we describe the P300 evoked response of one patient at Pz (the electrode where the P300 is typically the largest) and at the same time look at electrodes where different components of the event-related potential entered classification.

The general idea behind a P300 BCI

Rows and columns flash randomly and sequentially. The user pays attention to a character. Each flash of the row or column containing the attended character serves as a rare event in an oddball sequence and elicits a P300 response. Users attend to one character (target) and ignore other characters (non-targets). A stepwise linear discriminant analysis (SWLDA) determines which character elicited the largest P300.

Patient A during training

Screen with P300 matrix

Average response of patient A after a target (red line) and after a non-target (green line). A positive deflection follows 200 ms after a target flashes.
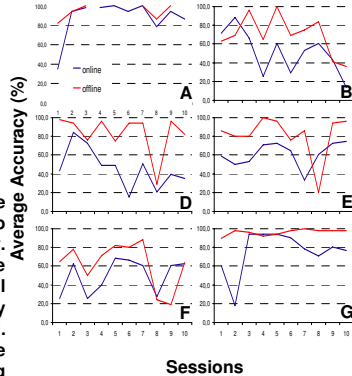
Methods Copy Spelling

Six patients with ALS (age range 36 to 67; 3 males) participated in 10 Copy Spelling sessions. A German sentence, which was divided in 10 to 14 runs, had to be copied with the P300 BCI. All rows and columns were flashed 20 times resulting 40 flashes per character. The German sentence contained all the letters of the alphabet and was 'Franz jagt im komplett verwahrlosten Taxi quer durch Bayern'. After ten online sessions, the offline performance was calculated using new stepwise linear discriminant analysis (SWLDA) parameters.
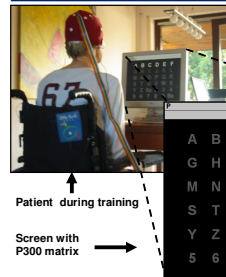
Methods Free Spelling

Four patients (A, B, E and G participated in additional Free Spelling sessions. During these sessions patients started with Copy Spelling runs (to warrant standard EEG analysis), but then continued with Free Spelling runs in which the patients could 'write' whatever they wanted. The goal was to reduce the number of flashes as much as possible while maintaining a sufficient accuracy (speed-accuracy trade off).

Results Copy Spelling

Overall Performance

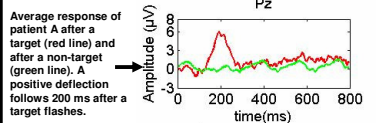Average online and offline accuracy (%) over all ten Copy Spelling Sessions

After ten online sessions three patients (A, E and G) were able to copy words with > 70 % accuracy. However, calculation of offline performance showed that all patients reached > 70 % accuracy when new weights were applied. Four patients chose to participate in the additional Free Spelling Study. (see right panel)

Individual online and offline Performance

Average Accuracy (%) over the Copy Spelling runs for each patient.

Results Free Spelling

Individual performance

User	# Free Spelling Sessions	Average Performance (%)	Number of Sequences	Selection Time/character (seconds)	character per minute
A	10	76,1	14	29,4	2,0
B	19	77,9	7	14,7	4,1
E	13	69,6	12	25,2	2,4
G	16	91,6	4	8,4	7,1

Number of sessions, average online performance, minimum sequences needed, time to select one character and number of characters per minute for each patient.
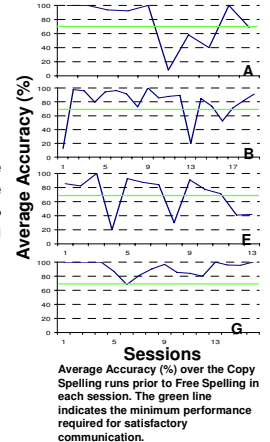
Patients A, B, E and G continued in the Free Spelling Study. All patients were able to write with an accuracy of over 70% correct. Some written phrases during Free Spelling (translated from German):

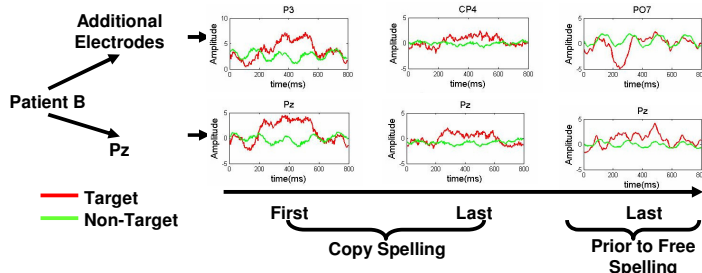'Life is always exciting, valuable and beautiful' (written in 19.6 minutes)

'I was in Freiburg last Saturday. I have bought new clothes' (13.3 minutes)

'The more I concentrate the worse I write' (10.1 minutes)

Performance curves

Average Accuracy (%) over the Copy Spelling runs prior to Free Spelling in each session. The green line indicates the minimum performance required for satisfactory communication.

Psychophysiological Results of Patient B

Additional Electrodes

Patient B

Pz

Target
Non-Target

First — Last — Copy Spelling

Last — Prior to Free Spelling

The figure (left) offers a closer inspection of the ERP's following targets and non-targets for patient B, who has completed 17 free spelling sessions (more than any other patient). From left to right the averaged response to targets (red line) and non-targets (green line) can be seen in the first and last Copy Spelling Session and copy spelling recorded on the same day as the last Free Spelling Session. In the bottom row the averaged response at the Pz electrode are plotted against time and in the top row averaged response at the electrode that received the largest SWLDA coefficient. The figure shows that electrode locations not typically associated with the P300 provide important additional and unique information for the SWLDA classification algorithm. E.g. Electrode location PO7 at 230 ms was given the largest SWLDA coefficient in the last session of Free Spelling.

Discussion

1) Results show that a P300-BCI is feasible for patients with amyotrophic lateral sclerosis. Offline analysis of the data provided >70 % accuracy for all patients. To test whether the P300-BCI could be used for communication 4 patients agreed to continue training and were provided with the Free Spelling system. All patients were able to achieve > 70 % correct online.

2) The advantage of the P300-BCI is that extensive training is not needed. However, the visual P300-BCI may not be feasible in patients with late-stage ALS, who sometimes have limited or no vision.

3) The P300-BCI is named as such because of the modified oddball sequence the paradigm employs. However, the SWLDA selects spatiotemporal features that most effectively discriminate target from non-target responses within a 0 – 800 ms window. Inspection of the classification coefficients shows that features other than the P300 are used for optimal classification. Most notably, features recorded from electrode locations PO7 and PO8.

4) Although a training period is not required, periodic adjustment of classification coefficients typically improves performance.