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Attention and working memory influence on P300-based BCI performance in people with amyotrophic lateral sclerosis

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Abstract

The purpose of this study was to investigate the support of attentional and memory processes in controlling a P300-based brain-computer interface (BCI) in people with amyotrophic lateral sclerosis (ALS). Eight people with ALS performed two behavioral tasks: i) a rapid serial visual presentation (RSVP) task, screening the temporal filtering capacity and the speed of the update of the attentive filter, and ii) a change detection task, screening the memory capacity and the spatial filtering capacity. The participants were also asked to perform a P300-based BCI spelling task. We found that only the temporal filtering capacity was a predictor of both the P300-based BCI accuracy and of the amplitude of the P300 elicited performing the BCI task. We concluded that the ability to keep the attentional filter active during the selection of a target influences performance in BCI control.

1 Introduction

The Brain Computer Interface (BCI) exploits neurophysiological signals to control external devices for a range of applications (Wolpaw & Wolpaw 2012). Reasons for performance variability across people with Amyotrophic Lateral Sclerosis (ALS) and performance predictors of P300-based BCI were not fully investigated. Indeed, the knowledge about the cognitive capabilities reflecting a successful use of P300-based BCI is limited. In particular, people suffering from ALS, included in the range of potential users of BCIs, could have cognitive dysfunctions in association with motoneuron failure, mostly regarded as attention, concentration and verbal fluency (Ringholz et al. 2005). In this study we investigated the influence of the attentive and memory features of people with ALS on performances in a P300-based BCI task.

2 Methods

2.1 Participants

We recruited the participants at the ALS center of the Policlinic “Umberto I” of Rome. We included in the study a total of nine volunteers, all naïve to BCI training, (3 women; mean age=59.7±12.3) with definite, probable, or probable with laboratory support ALS diagnosis (mean ALSFRS scores: 32.4± 8.2; Brooks et al. 1996). Inclusion criteria required that participants were able

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to communicate with or without the help of an AT device which also included an eye tracker, thus all participants had their eye-gaze control preserved. Due to the fact that one participant did not perform the behavioral tasks, only the data of 8 participants out of nine (3 women; mean age=58±12; mean ALSFRS sores: 31.8±8.6) were reported in this article.

The study was approved by the ethic committee of Fondazione Santa Lucia, Rome and all participants provided an informed consent.

2.2 Experimental protocol

The experimental protocol consisted in two sessions performed on two different days. In the first session participants were asked to copy spell seven predefined words (5 characters each) by controlling a P300-Speller (Farwell & Donchin 1988). The EEG was recorded using 8 active electrodes (Fz, Cz, Pz, Oz, P3, P4, Po7, Po8). All channels were referenced to the right earlobe and grounded to the left mastoid. EEG was amplified using an 8 channel EEG amplifier (gMobilab, g.tec Austria) and recorded by the BCI2000 software.

During the second session, temporal attention capabilities of participants were screened using a rapid serial visual presentation (RSVP) task: two targets were embedded in a stream of distracter stimuli, all presented at central fixation at a presentation rate of 100ms each. Distracters were black capital consonants. The first target (T1) was a green letter. The second target (T2) was a black capital “X”. In 20% of trials T2 was not present, whereas it followed T1 with no (lag 1), one (lag 2), three (lag 4) or five (lag 6) intervening distractors in 20% of trials for each condition. Subject was asked to decide whether the green letter was a vowel and whether the black X was contained in the stimulus stream (Kranczioch et al. 2007).

Memory capacity and attentional spatial filtering capacity were screened by means of two change detection (CD) tasks: a baseline task and a selection task (Vogel et al. 2005). In the baseline task the memory array consisted of three or four rectangles of the same color (all blue or all red) with one out of four possible orientations (vertical, horizontal and two diagonals), presented for 100 ms. The memory array was followed by a retention interval of 900ms and then by a second array of rectangles (test array). The participants were asked to report if the orientation of the rectangles in the test array was identical to the one in the memory array. In the selection task, each memory array consisted of six or eight rectangles. Half of the rectangles were blue and the other half were red. Participants were instructed to memorize the rectangles of one color and to ignore the rectangles of the other color. They were then asked to report if the spatial orientation of the memorized rectangles in the test array was identical to the one in the memory array.

Due to the possible motor disabilities of the experimental group, participants were asked to give a binary response (yes or no) to the operator with the residual communication channel.

3 Data analysis

EEG data was high pass and low pass filtered with cut off frequencies of 0.1 Hz and 10 Hz respectively using a 4th order Butterworth filter. In addition, a notch filter was used to remove 50 Hz contamination. Data was divided into 1000 ms long epochs starting with the onset of each stimulus. The amplitude of the P300 potential in Cz was defined as the highest value of the difference between target and non-target average waveforms in the time interval 250-700ms (P300amp).

To provide an estimate of the classifier accuracy we considered the binary classification problem target vs. non-target (binary accuracy, BA; Blankertz et al. 2011). A 7-fold cross-validation was used to evaluate the binary accuracy of the classifier on each participant’s dataset by applying a Stepwise Linear Discriminant Analysis (SWLDA) on the testing dataset (6 words) and assessing the binary accuracy on the training dataset (the remaining word).

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The detection accuracy of T1 (T1%) in the RSVP task was considered as an index of the temporal attentional filtering capacity of the participants. Because the detection accuracy of T2 (T2%) was considered as an index of the capability to adequately update the attentive filter, only trials in which T1 had been correctly identified were selected in order to determine T2%.

To investigate the memory capacity, according to Cowan (2001), we defined the number of items held in memory (K) as K=S(H-F), where S is the size of the array (highest number of item to memorize, S=4), H is the observed hit rate and F is the false alarm rate. We calculated the K index for the baseline task (Kb) and for the selection task (Ks). To screen for the attentional spatial filtering capacity (α), of the participants (that is the capacity to efficiently filter the distracters) we subtracted the Ks from the Kb (α= Kb- Ks).

Because variables were normally distributed, Pearson's correlation coefficient of T1% and T2% with the BA and the P3amp was computed. Because Kb and α violated the assumption of normality, they were correlated with BA and P3amp by means of the non-parametric Spearman correlation test.
For the parameters whose correlation was statistically significant we performed two regression analyses in which attentional parameter (T1%) was considered as the independent variable and the BA and the P300amp variables were considered as dependent variables.

4 Results

A significant positive correlation was observed between T1% and the offline BA, r=.79, p<0.05. To estimate the predictive value of T1% on the binary accuracy we computed a regression analysis which resulted in an F=8.341 with a p<0.05, indicating that the variance of the binary performance was predictable by the participant temporal filtering capacity, with ß=0.79. A significant positive correlation was found between T1% and P300amp (r=.84.5, p<0.05) showing that participants with higher T1% had a larger P300amp. As a result of the linear regression, T1 accuracy was significantly predictive of P300amp (F=16,23 with a p<0.05) with ß=0.87. Offline mean value of BA obtained during the BCI task was 87.4% (SD = 2.4%, range = 84.5–92.3 %). The mean amplitude for P300 was 3.3 μV (SD = 1.6, range = 1.1–6.5 μV). Mean accuracy of detection was 77.2% (SD = 10.4%, range = 65–96.25%) and 67.7% (SD= 14.1%, range = 50.3–87.1%) for T1 and T2, respectively. No significant correlation was found between T2%, Kb, α the offline binary performance and P300amp.

5 Discussion and conclusion

The detection rate of T1 in the RSVP task can be interpreted as an index of selective attention: it represents indeed the capacity to detect a target within a stream of stimuli, to create a memory trace and to retain it. We demonstrated that such capability influences the performances in the BCI task.

As the accuracy of detecting T2 is an index of the speed of attentive update, the missed correlation with the considered BCI variables leads us to speculate that the capacity of dynamically updating the attentive filter is less likely to be a cognitive substrate supporting the BCI control.

The lack of relationship between BCI parameters and the variables measured with the change detection task did not confirm the hypothesis that the memory capacity and the attentional spatial filtering capacity were associated with the capability of the participants to control the P300-speller. We can speculate that the allocation of attention resources on the selected item during the BCI task might not be based on spatial (being the location of the target letter static) or feature characteristics but on symbolic aspects (e.g. semantic aspects of the target letter).

The data reported in the present paper partly clarify the cognitive substrate related to BCI control in people with ALS. This issue could allow future speculations on the factors underlying BCI control

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failure observed in potential user groups. The awareness about the processes and the clinical features of BCI potential end-users influencing the BCI performance, would allow developing flexible systems, adaptable to different clinical profiles. We can conclude that top-down mechanism to keep an attentive map active (Huang & Pashler 2007) is crucial to control a BCI speller task, allowing the user to set up and maintain the proper attentional map throughout a trial and thus to select the desired letter.

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