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ERP assessment and EEG/fNIRs communication in a patient with a disorder of consciousness

Sandra Veser[1*]; Boris Kotchoubey[1], Bin Xia[1] and Niels Birbaumer [1]
[1] University of Tübingen, Germany
sandra.veser@googlemail.com

Abstract

To examine the presences of electrophysiological indicators, by measuring event-related potentials (ERPs), is one solution to detect residual cognitive functions in patients with disorders of consciousness (DOC). To investigate such a patient, different kinds of stimuli like tones, words, and sentences were used with and without instruction and were hierarchically ordered according to the needed processing steps. In addition, the patient performed a semantic computer-brain-interface (BCI) while electroencephalography (EEG) and near-infrared spectroscopy (NIRs) signals were recorded. We found evidence that the DOC patient was able to follow active instructions and to shift his attention, but had only limited control of the BCI performance.

1 Introduction

One way to detect the residual cognitive functions in brain-damaged patients, who has lost the ability for behavioural performance, is to measure their brain responses, for example using event-related brain potentials (ERPs). This approach has been successfully reported in a number of studies (e.g., Cruse, Chennu, Chattele, C, Bekinschtein, Fernández-Espejo, Pickard et al., 2011; Daltrozzo, Wioland, Mutschler, Lutun, Calon, Meyer et al., 2009, Kotchoubey, Lang, Mezger, Schmalohr, Schneck, Semmler et al., 2005; Schoenle & Witzke, 2004) and indicates that the brain of such patients might be able to process information at various levels of complexity including semantic information as well as understanding active instructions like silent counting or even attentional shifts (e.g., Boly, Garrido, Gosseries, Bruno, Boveroux, Schnakers et al. 2011; Monti ; Vanhaudenhuys, Coleman, Bol, Pickard, Tshibanda, et al., 2010).

In addition, brain responses can be used to set-up a communication channel by a so called Brain Computer Interface (BCI) for patients who are severe paralysed and cannot communicate by any other means. The brain responses of those patients can be controlled by using electroencephalography (EEG; e.g., Birbaumer, Ghanayim, Hinterberger, Iversen, Kotchoubey, Kübler, et al., 1999) or functional-near infrared spectroscopy (fNIRs; e.g., Gallegos-Ayala, Furdea, Takano, Ruf, Flor, Birbaumer, in press). Here, we wanted to investigate whether a good outcome in the cognitive assessment using ERPs leads to good BCI performance.

[*] Masterminded EasyChair and created the first stable version of this document

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2 Methods

A 60 year old, male patient, diagnosed was minimally conscious state (MCS: Giacino, Ashwal, Childs, Cranford, Jennett, Katz, et al., 2002) and having a CRS-R score of 23 participated in four sessions. In the first and second sessions he was assessed by using several passive and active ERP assessment paradigms. In the other two sessions he performed a semantic BCI with two answer categories.

2.1 ERP Assessment

ERP paradigms. (1) A multifeature oddball paradigm principally adapted by Näätänen et al. (2004). The standard stimuli were harmonic tones (440+880+1760 Hz) with a duration of 75 ms and an intensity of 70 dB, presented binaurally via headphones. 50 % of all stimuli were standards. The other kinds of stimuli were presented with the frequency of 5% each. Two of them differed from the standards by their pitch (f; 220+440+660 Hz and 880+1760+2640 Hz), two by their duration (d; 50 ms and 100 ms), two by their location (l, left or right monaural presentation), two by intensity (i, 50 dB and 90 dB) and two by complexity (c; 440+1760 Hz and 440+660+880+1760 Hz). The SOA was 500 ms. (2) A frequency oddball paradigm. The paradigm used a frequent complex tone (Standard: 440+880+1760 Hz) and a rare complex tone (Deviant: 247+494+988 Hz) with an ISI of 850 ms. (3) A word-prime paradigm. The paradigm tested semantic processing at the word level. 200 pairs of words spoken by female voice were presented. 100 pairs contained semantically closely related words (e.g., cold - warm) and the other 100 words containing unrelated words (e.g., cold - green). The ISI within word pairs were 400 ms and between word-pairs were 900 ms. (4) A sentence understanding paradigm, to test semantic processing at the sentence level. 200 sentences were used and in 100 of them the last word was highly expected in the context (e.g., the eel is a fish), while in the remaining sentences the ending was semantically incorrect (e.g., the eel is a bird). ISI between sentences were 900 ms. (5) An oddball paradigm with the same stimulation as in (2). In addition, the patients received the instruction to count the deviants. (6) A dichotic listening paradigm. It used a word stream containing five semantic categories (animals, professions, tools, body parts and household objects). The words were presented alternating to the left and right side with a jittered ISI between 150-300 ms. The patients' task was to attend to one side and count the animals of the attended side.

The EEG was recorded according to the international 10-20 electrode system with 31 active electrodes (F3 Fz F4 FC5 FC1 FCz FC2 FC6 T7 C3 Cz C4 T8 CP5 CP1 CPz CP2 CP6 P7 P3 Pz P4 P8 PO3 POz PO4 O1 Oz O2). The signal was digitized at 512 Hz and filtered with a bandpass filter between 0.1 Hz and 100 Hz. The vertical and horizontal electrooculogram were recorded. Offline, the EEG was filtered using a Kaiser low-pass at 25 Hz with 1856 points and ocular artifacts were corrected. The continuous EEG data were split into epochs, respective of the paradigm. In addition, trials of each type of categories were averaged. Difference waves were obtained by subtracting the standard from the each of the deviants. Finally, we computed a running *t*-test to evaluate whether the difference waves were significantly different from the baseline in the time range of the respective components.

2.2 EEG/FNIRs BCI

Like in the sentence understanding paradigm of the previous section, the patient was presented with correct and incorrect sentences grouped in 20 sentences in each block. A total of four blocks per session was presented. After each sentence the patient's task was to think "ja" (yes), if the sentence was correct and "nein" (no) if it was incorrect (Figure 1A) while EEG (using the same electrode set-up as in the assessment) and fNIRs (Spectratech OEG-Sp02, Spectratch Inc. Japan) data were recorded simultaneously with a sample rate of 12.2 Hz. 16 optodes were placed at the forehead. The

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EEG data were preprocessed similarly to the method used above and then t-CWT analysis for feature classification (Bostanov et al. 2004). For fNIRs data we used the mean amplitude for each channels of the oxyhemoglobin. For both ERP and fNIRs data, we used a support vector machine to classify the correct and incorrect answers using a grid searching to find the best parameter und using a five-fold cross-validation. We trained the model using the first 3 blocks and tested the last block. In addition, we calculated the coincidences of the correct detected classification results of EEG and fNIRs.

3 Results

3.1 ERP Assessment

In Table 1 we show the summarized results of the all expected ERP components. In the (1) multifeature paradigm 3 deviant elicited the expected ERP component, the mismatch negativity (MMN). In the frequency oddball (2) we also find the expected P3 component as well in the counting oddball task (5). However, the P3 component in the active task was not larger than in the active condition, thus, it is not clear whether the P3 component of the active counting task includes really active counting contingence. In addition, we found a N400 component in the sentence understanding paradigm but not in the word-priming paradigm. Further, we obtained a side specific effect in the dichotic listening task, where the P3 component for the attended side was enhanced as compared with the unattended side.

(1) mutifeature					(2) frequency	(3) word-prime	(4) sentence	(5) counting	(6) dichotic	
d	f	i	l	c					left	right
-	+	+	+	-	+	-	+	+(-)	+	+

Table 1: Results of the ERP assessment paradigms: + is expected ERP component was present; - expected ERP component was absent.

3.2 EEG/fNIRs data

The results using EEG and fNRIs classification are depicted in Figure 2B. As it can be seen, the results of the EEG/fNIRs data for each method alone are above or equal the theoretical chance level (55 % with alpha = 0.5; Müller-Putz G et al. 2008). However, the coincidence (trial was correctly identify with EEG and also fNIRs) of correctly classified trials was below the chance level.

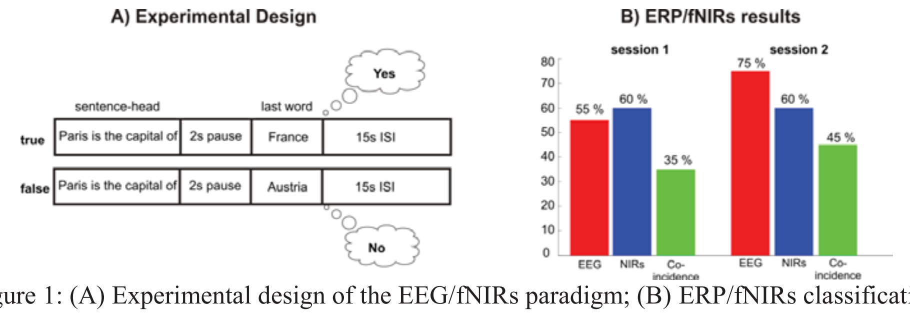

Figure 1: (A) Experimental design of the EEG/fNIRs paradigm; (B) ERP/fNIRs classification results

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4 Discussion and Conclusion

We found evidence in the ERP assessment that the MCS patient was able to perceive and process various aspects of his environment, including speech perception. Moreover, he was able to modulate his attention. Even so, the technique still need to become more precise and is not yet capable of exact assessment in each individual paradigm (we found no N400 component in the word-prime paradigm but in the sentence paradigm). It is useful to assess the presence of higher cortical functions in patients who cannot express themselves behaviorally before applying a BCI.

BCI performance of this patient measured with EEG was slightly above the theoretical chance level in the first session but improved in the second session. Without the knowledge of the results of the ERP assessment, the BCI results of the first session would be quite discouraging for patients and their caregivers and might lead to aversion for training a BCI by itself because negative online results enhances the pressure on the patient and induces negative emotions. Furthermore, the data of the NIRs BCI were identical in both sessions. It should be noted that NIRs does not depend on the quality of the data which causes trouble in the EEG, like electricity flow of the surrounding but have other influences like the physiological noise or movement artifacts. Thus, combined EEG and fNIRs BCI seemed to be a promising tool for further BCI applications if it was shown that the patient is able to perceive and process complex stimulation.

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