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Steady-State Somatosensory Evoked Potentials in Minimally Conscious Patients – Challenges and Perspectives

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Abstract

In the present study, we aimed to detect the "resonance-like" frequencies of the somatosensory system in patients in a minimally conscious state using a screening paradigm. EEG measurements were conducted in seven patients during tactile stimulation of their left and right wrist. A significant tuning curve could be found in one of the patients. Various reasons that could explain the inconclusive outcome of most measurements, as well as future perspectives are discussed.

1 Introduction

A brain-computer interface (BCI) based on electroencephalography (EEG) can provide severely brain-injured people with a new output channel for communication and control [8]. BCIs may also be used as an objective and motor-independent diagnostic tool for patients with disorders of consciousness (see [1] for a review). For patients with impaired hearing or vision, BCIs based on tactile stimuli could be one possible alternative since the somatosensory system is expected to remain functional [4]. By repeatedly applying tactile stimuli with a sufficiently high rate, steady-state somatosensory evoked potentials (SSSEPs) can be evoked and measured using EEG [7]. SSSEPs can intentionally be modulated by attention [2] and, therefore, are one possible way to realize a tactile BCI [4].

As a first step to realize such an SSSEP-based BCI in patients with severe neurological diseases or brain injuries, the "resonance-like" frequencies, i.e. the frequencies with the highest SSSEP response of the somatosensory system [3] need to be identified. Within our work, a well-established screening paradigm was adapted for this purpose to be applied to patients in a minimally conscious state (MCS), i.e. to patients showing non-reflexive behavior but being unable to communicate. Challenges, problems, and results of this attempt are presented. Possible improvements and reasons why the results are not as promising as expected are discussed.

2 Materials and Methods

2.1 Screening Paradigm

Two C-2 tactors (Engineering Acoustics, Inc., USA) were attached to the left and right volar wrist using elastic wrist bands. The wrists were stimulated with seven frequencies ranging from

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14 to 32 Hz (3 Hz steps). A modulated stimulation pattern (200 Hz sine carrier), generated by a self-made, medically approved stimulation device [5], was used.

Each trial started with a 2.5 s reference interval without stimulation, followed by seven 2 s stimulation intervals with frequency and wrist randomly chosen (without using the same frequency and wrist twice in a row). To avoid attentional modulation effects of the SSSEPs, relaxing music was presented via headphones to distract the participants. The whole paradigm lasted around 40 minutes and consisted of 40 repetitions per frequency and wrist.

The EEG was recorded with two g.USBamps (g.tec medical engineering GmbH, Austria) using 32 active electrodes. The reference electrode was connected to the left earlobe, the ground electrode to the right mastoid. Bipolar channels were derived at three frontal, seven central, and four parietal positions (international 10-20 system). Tuning curves showing the percentage band power increase of the stimulation intervals relative to the reference intervals [3] were computed. For statistical validation, 95 % confidence intervals were estimated by bootstrapping using 1000 bootstrap samples.

2.2 Participants

Seven patients in an MCS participated in this study (one or two sessions) at the Albert Schweitzer Clinic (Graz, Austria) and the Liège University Hospital (Liège, Belgium). The patients were either sitting in a wheelchair or lying in bed with the upper part of their body slightly elevated. Before or after each EEG measurement, the patients were behaviorally assessed using the Coma Recovery Scale-Revised (CRS-R). Table 1 provides clinical and demographic data together with the CRS-R scores of all patients. Informed consent was obtained from the patients' legal representatives. The study was approved by the Ethics Committees at the participating institutions and was conducted in accordance with the Declaration of Helsinki.

Patient no.	Location	Age (years)	Sex	Etiology	CRS-R s1	CRS-R s2
PA_{01}	Graz	28	male	Traumatic	9	11
PA_{02}	Graz	58	female	Anoxia	8	10
PA_{03}	Graz	67	male	Traumatic	17	17
PA_{04}	Liège	22	male	Traumatic	6	–
PA_{05}	Liège	15	male	Hemorrhagic stroke	15	–
PA_{06}	Liège	51	female	Hemorrhagic stroke	4	–
PA_{07}	Liège	45	female	Traumatic	7	–

Table 1: Clinical and demographic data of the patients, together with the CRS-R scores of the first (s1) and, where applicable, second (s2) session.

3 Results

Fig. 1 shows the SSSEP screening results of all patients and sessions from three representative EEG channels contralateral to the stimulated wrist. Only in one patient, PA_{05}, a significant tuning curve could be found for right wrist stimulation at the bipolar channel F3-C3. The frequency with the highest relative bandpower increase (140 %) was found to be 20 Hz. In all other patients, no significant tuning curves were found at any of the channels contra- or ipsilateral to the stimulated wrist. To demonstrate that the screening paradigm is suitable

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to identify the individual "resonance-like" frequencies, the results of a healthy control were included (same tactor location; reduced channel set only), showing high tuning curve peaks at 23 Hz for left (373 %) and right (363 %) wrist stimulation.

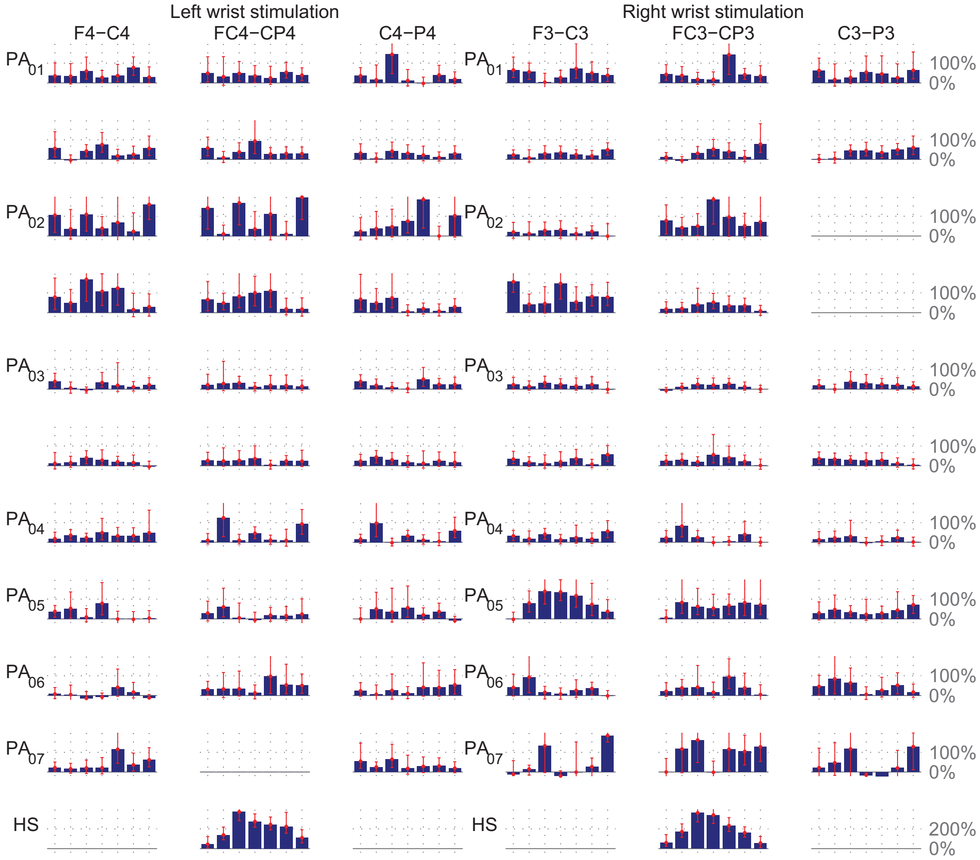

Figure 1: Screening results of all patients and sessions (rows) from three representative (bipolar) EEG channels contralateral to the stimulated wrist (columns). The bars show the relative bandpower increase (in %) with 95 % confidence intervals of all seven stimulation frequencies. The last row shows the results of a healthy subject (HS), using a different y axis scaling.

4 Discussion

Within this work, a screening paradigm was developed with regard to the specific needs and capabilities of patients in an MCS. The wrists were selected as target location, since some of the patients suffered from hand spasticities, making it not easily possible to use more sensitive locations like finger tips. Screening results obtained from a healthy control were totally in accordance with literature (e.g. [3]). However, only in one of the seven patients, a significant tuning curve could be found. In all other patients, stable SSSEPs were not present. In some patients, an increase in band power of only certain single frequencies could be found. However,

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it is not yet known if perhaps such frequencies could intentionally be modulated and thus be sufficient to realize a BCI. While technical problems seem unlikely (as shown by the control experiment), various other reasons could explain the inconclusive outcome of most patient measurements. First, uncontrolled body movements of the patients resulted in a huge amount of biological (EOG, EMG) and technical (cable movements, electrodes touching the pillow) artifacts. Even though trials containing strong artifacts were manually remove, outliers and huge confidence intervals were still present in the screening results. Second, it was not clear if the position and contact pressure of the tactors allowed the patients to perceive the stimuli strong enough at all, as they could not be simply asked about their perception of the stimuli. Spasticities may have also had a severe influence on the SSSEPs, since the tendons of the finger flexors are located at the volar side of the hand. Third, maybe SSSEPs were not present because of an impaired somatosensory system, or could simply not be measured with EEG due to alterations in the brain topology. Interestingly, the one patient showing significant results was a stroke survivor with a CRS-R score of 15. In comparison to the others, this patient had a high score and no traumatic injury. This could be evidence that the structures in his brain were not that damaged and therefore SSSEPs could be measured.

Similar difficulties regarding a paradigm transition from healthy subjects to patients in an MCS were already reported in [6]. In future, better artifact avoidance or rejection methods, longer stimulation intervals, or other target body locations could be beneficial. Moreover, a thorough neurophysiological examination prior to SSSEP measurements may be helpful.

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